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CROP ROTATIONS AND SUMMER CROPS FOR FORAGE PRODUCTION IN NORTHWESTERN SPAIN (GALICIA)

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Crop rotations and summer crops for forage production

in northwestern Spain (Galicia)

by

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INTRODUCTION

This dissertation, intended to contribute to the knowledge of the forage production in Galicia (Spain), is divided into two parts: (a) a study of several crop rotations for the production of forages and (b) a comparison of several summer crops for forage production. Galicia is the region located in the northwestern corner of Spain. From the agricultural point of view, the region has several features that differentiate it from the rest of the country. The most important are the climate and the farm size. Its annual average rainfall ranges from 800-1800 mm depending on the area within the region. This factor makes Galicia one of the most humid areas of Spain. The temperatures are mild in the coastal areas and more extreme in the interior. The farm size is very small with 99% of them less than 20 ha and 59% less than 3 ha. With these conditions, the kind of agriculture practiced in many farms is part-time farming or just subsistence farming which only produces food and forages for the farmers and their livestock with very little production for marketing. Their main crops are corn, potatoes, beans, prairies, rye, turnips, small grains for forage, wheat and Italian ryegrass and the most common crop rotation is

$$\begin{array}{c} \text{corn} \\ \text{or} \\ \text{potatoes} \end{array} \rightarrow \begin{array}{c} \text{rye} \\ \text{or} \\ \text{wheat} \end{array} \rightarrow \text{turnips} \quad .$$

As a consequence of the farm size and the kind of agriculture, the farmers have a low standard of living, and the young people leave the rural areas for the cities where they can find better job opportunities.

During recent years and because of the development of the dairy industry, the production of milk has expanded and now it is the main source of regular income for many of the farms. For this reason, the traditional cropping systems are changing to a more intensive forage-oriented system and pasture production.

In Galicia, the production of several crops and pastures in different areas and conditions is known, but no direct comparison of the whole rotation with prairies has been made. The basic concept of the first part of this dissertation is to determine and compare the quantity and quality of the forage production of several important Galician crop rotations and types of pastures. The data obtained in this crop sequence research will be a basic step in the knowledge of the forage potential of the land.

The second part of this dissertation is dedicated to the study of summer crops. The interest of these crops is severalfold: (a) corn is the main summer crop in Galicia, but in several areas other crops may be more productive or economical; (b) many farmers do not make silage, but in order to feed their livestock during the summer, they need to have a source of green forage; (c) in pasture production systems, a renovation of the prairies has to be done periodically and the seed bed preparation is easier and better done if a row crop is planted in between; and (d) to know the production features of the summer crops is a necessary step in order to improve the actual cropping systems.

We think that this kind of research conducted in Galicia is most needed for getting the maximum from this region's farm land and in order to find the optimal economic, productive and convenient forage system for this part of Spain.

LITERATURE REVIEW

Galicia: Basic Physical, Agricultural and Sociological Facts

Physical features (22, 72, 233)

Galicia is located at the upper northwest corner of Spain above Portugal, at 42°-43° latitude. The geographical area of this hilly region, that limits with the Atlantic Ocean and Cantabric Sea, is about 2,942,000 ha. Its highest mountains are situated in the oriental part (Peña Trevinca 2,030 m, and Cabeza de Manzaneda 1,778 m). Its rainfall is quite abundant and ranges from around 800 to about 1800 mm depending on the area within the region, although its distribution is not uniform during the different months of the year. The fall and winter months receive most of the rainfall, while the summer is generally dry (June, July, August).

The temperature of Galicia is mild in the coastal areas and more extreme in the interior and higher parts of the region. The winter mean temperatures (December, January, February) range from about 2.5 C for the oriental mountainous region to about 10 C for the coastal zone; and during the summer (June, July, August), they range from around 16 C to approximately 21, with the southern and interior zones the warmest.

The soil types of Galicia change depending on their parent material of which the most important are granites and schists. In general, Galicia soils are quite acid with a mean pH (KCl extraction) of about 4-5, and low in phosphorus content.

Agricultural features (22, 176, 197)

Of the total geographical area, only about 20% is covered by crops. See Table 1.

Table 1. Land distribution in Galicia

Occupation	Thousands of ha	% of the total
Cultivated land	549	18.7
Natural prairies and hill land	321	10.9
Forest and bushes	1,879	63.8
Other	192	6.6
Total area	2,942	100.0

The main Galician crops and their surface are presented in Table 2.

Table 2. Most important crops in Galicia

Crop	Approximate area (thousands of ha)
1. Corn (grain and forage)	200
2. Potato	104
3. Beans	84
4. Sown prairies	71
5. Rye	53
6. Turnips	54
7. Small grains for forage	46
8. Wheat	33
9. Italian ryegrass	30
10. Kale	8.9

There are also other crops not included in this list such as oats for grain, forage beets, etc. The table does not show the woody crops such as fruit trees and vineyards that occupied around 33,000 ha and the horticultural species.

The main fact about all these crops is that most of the varieties grown in the area are local ecotypes, except for potatoes, the sown prairies and for about 20-25% of the corn. The peculiarities of these crops will be exposed in the sections dedicated to each crop. Another interesting point is that even if the crops are similar throughout the regions, the crop rotations differ from one area to another in the regions. The distribution of crops depends mainly on the weather, soil conditions and on the technological and marketing aspects of the area.

There are several crop rotations, but the most common three are:

(a) Corn → Italian ryegrass (intercropping) or *Avena* ssp (2 crops, 1 year)

(b) Corn or potatoes → rye or wheat → turnips (3 crops, 2 years)

(c) Rye (fallow) (1 crop, 2 years)

The sown prairies are relatively new crops, although they were introduced at the beginning of the century. Their expansion started about 1960 and their development depends on changes in sociological and marketing conditions of the area.

Most of the crops are rain-fed, but in the hottest areas, summer irrigation is used if water is available.

Sociological, structural and economic features (22, 70, 176)

A review of the sociological, structural and economic aspects of the region as related to agriculture will help to better understand the conclusion reached in this dissertation. This region of Spain differs because of the small and divided farm size. Forty percent of the farms have between 3-10 ha and only 2.7% of them have between 20 and 100 ha. According to the definition reported for Central America (237), small farmer is one that has less than 7 ha and practices traditional crop husbandry methods. This definition could be, in general, also applicable to Galician conditions. With these sizes, it is very hard to get a fair standard of living unless they are dedicated to horticulture (which is not always possible because of climate and marketing conditions), or unless they work as part-time farmers (which is very common, mainly near the bigger towns). For these reasons, when the Spanish and Central European industrial growth boomed (mid 60s-70s), most of the young people left the rural areas to the industrial cities of Spain and Europe, and consequently the average age of the farmers raised. Presently, few young people want to be farmers.

Traditionally, the crops and their cropping systems were mainly aimed to provide the food needs of the family (self-consumption) and only some surplus of potatoes or some beef for finishing were marketed. This farming system in particular has been changing in the last years because of the development of the dairy industry, and now the main activity of many of the farms is the production of milk. This regular source of cash is forcing the farmers to change to more intensive forage production systems relying on the following: (a) intensive crop rotations and (b) improved pasture production. The first (a) is the direction taken by other regions with similar structural problems like Bretagne (France) (87, 253). Intensive crop production (corn → Italian ryegrass) generally raises the forage output of the farm, although it requires more labor and more financial capability apart from the time requirements at the seeding and harvesting times. Pasture production (b), compared with annual crops, has several factors that facilitate its expansion such as: greater forage yields, less labor requirement, cheaper machinery operation, and less cash flow requirement. These are reasons that made the pasture production very popular in Galicia and many of the farmers put almost all their land to pasture when they change to this cropping system. Pastures are very important crops for increasing forage production on hilly lands, but their use on farm land adequate for forage crops is a matter that needs a deep agricultural, economical and sociological analysis and the best use depends on many factors. One of the most important, for the family with a small farm which wants to have a fair standard of living, is land productivity.

Although a fair amount of research has been done in several aspects of the Galician agriculture (22, 202, 205, 206, 248), a basic comparison of the productivity of several current cropping systems with pastures has never been made.

Crop Rotations

Before discussing the forage systems and the crops involved, which will be discussed in posterior sections, a brief review of crop rotations will be given. This subject has been a matter of great attention since the early agricultural reports (306, 326). Although everybody has the general idea of the meaning of a crop rotation, its definition changes a little depending on the background and country of the author (7, 73, 296, 339). Maybe the most general and understandable definition is one reported by Andrews and Kassam (7). Rotation is the repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land. One cycle often takes several years to complete. On the other hand, there is a blurry distinction between crop rotation and crop sequence. Some authors define this as a geographical distribution of the crops at a given time of year (73).

Crop rotations have been reported to be advantageous in many ways (4, 11, 171, 296, 306, 324).

Soil fertility

This feature of the crop rotations has maybe been the most extensively studied and reported (32, 74, 148, 171, 180, 223, 266, 289, 292, 306, 310). It includes different aspects such as soil physical properties, organic matter, soil N, erosion, etc. Early reports (171, 326) on agriculture stressed the importance of rotation to maintain or improve soil fertility. It is well-known that before the general use of fertilizers, nutrients and organic matter were returned to the soil primarily with farm manure, green manure and the growing of legumes in the rotation (4, 110, 166). For alfalfa and legume growing areas, those crops were considered essential in all crop rotations (13, 40, 73, 74, 171, 223, 310, 324), and many experiments showed their positive effect on the following crop (13, 40, 120, 148, 289, 292, 297). The use of grass and grass-legumes meadows has also been reported beneficial for soil fertility and for the next crops (13, 73, 171, 272, 289, 310). On the other hand, these prairies may be detrimental for the next crop because of the reduction of the water available for the next crop (257).

Reduced pest and weed risks

An extensive review about the effects of crop rotations on plant diseases has been done by Curl (62). It is well-known that some cereals cannot be grown continuously on the same field because of the buildup of plant diseases. Take-all disease of wheat, rye, etc. in the humid regions is a good example (4). For this reason, in England a break crop is used. This is a crop between two main cereal crops in order to reduce the soil diseases (110, 180). Nevertheless, some of the specialized vascular wilt pathogens produce microsclerotia or chlamysdospores that will survive many years in the soil (4). For all these reasons, crucifers are usually grown in rotation with other crops, so that a cruciferous crop is on the same field only once in every 3 or 4 years (110, 180, 296).

It is well-known that prior to the use of chemicals, rotating crops helped to control certain weeds (4, 110). Weed control by crop rotation is more likely to be successful when the growth and characteristics of a crop are in sharp contrast to those of the previous crop and the predominant problem weeds (296). With the same idea, Leighty (171) wrote that weed problems are likely to be least severe on farms where crop diversification is practiced and most severe on farms devoted for one reason or another to a single crop.

Another problem to consider with crop rotations is allelopathy (265). Farmers and researchers have referred to "soil sickness" problems since the beginning of agriculture. Many chemicals are produced in decaying plant residues, and some of them have been shown to be phytotoxic in laboratory experiments. Soil microorganisms also produced many toxic substances during the decomposition of plant residues.

Improved labor distribution

Obviously, the peak labor needs for various crops comes at different times and therefore the greater the variety of crops grown, the better the distribution of labor (4, 11).

Reduced risk due to price or yield variability

Since the various crops have different ideal weather requirements, growing a variety of crops is one way to build greater stability into the total cropping systems (4, 11, 171). Whether growing several crops to reduce the seasonal risk is a real advantage is questionable because it requires the substitution of lower value crops for the highest value crops on part of the acreage.

On the other hand, crop rotations also have several disadvantages, mainly because it is more difficult for the farmer to be an expert in several crops at the same time (4), and also because to grow several different crops may require different types of machinery, increasing the expenses of the farm and the fixed costs per hour of the implements because they are used less.

Present time

It was commented earlier that crop rotations were very important and maybe essential before the use of chemical fertilizers, herbicides and pesticides became a normal practice. All these products have made rotations agronomically unnecessary, and this new technology has given the farmers greater freedom of choice (4, 110). Nevertheless, since the energy crisis, the general rise in cost of agrichemicals along with their possible adverse soil and environmental effects, crop rotations may again be a subject of renewed interest (236, 324) in Western countries. In some European countries, this interest was never lost (42, 102).

Forage Production Systems

Forage production for ruminants is not a simple subject. It involves all the elements related with the production of forage crops and the use of forage by the animal. The reason for this is because forages are not valuable for themselves but they are an essential intermediate step in the animal production scheme.

There are many different animal growing systems based on forages. Some animals are on pasture while others are in dry lots, some receive green fodder, others receive conserved forages and still some are in mixed forage-grain rations. Many combinations of all these techniques are used. However, all these animal production strategies are based on forage production techniques and both together form a single unit that can be called an animal-forage system. These animal-forage systems are not only the result of forages being able to grow in a particular area and the kind of animals that can be raised, but also of the economic component of the whole scheme, which probably is the most important factor.

It is clear that there are many aspects of the forage production systems that could be reviewed such as crop forage production and quality, cropping systems, animal transformation and production, economics of the system, etc. For the type of research that has been conducted in this thesis, the literature review is going to be mainly dedicated to the crops used in the field experiments and to the analysis of different forage production systems practiced. These are going to be the ones that have, or may have, some similarities with the systems followed in Galicia.

Many forage and forage-grain systems have been reported around the world (7). They can be, for example, as intensive as corn intercropped with Italian ryegrass, as it is practiced in Galicia (176), or as extensive as some hill grazings that have never been cropped, fertilized or improved (166). In general, the grasslands systems are considered to be more extensive and less costly than the row cropping systems (118, 215, 287). It is clear that there is a lot of variation among grassland systems and among cropping systems and some definitions and classifications could be useful in order to visualize the differences.

To Holmes (128), the term grassland refers to a plant community in which grasses are dominant, shrubs are rare, and trees absent. Piper (252) defined pasture as a field or area covered with grass or other plants (commonly herbaceous) and used for grazing animals. Lazenby (166) in Britain made the following land and grassland classification:

1. Enclosed grassland

tillage leys	arable land
reseeded grassland old grass	permanent grassland

2. Rough and hill grasslands

This classification is based on several degrees of land quality and production intensity. The tillage land is normally dedicated to annual crops, and it is not a grassland, while leys are temporary grassland that can be of short or long duration. They are often associated with high capitalization and with dairying as a major enterprise, and are the highest production intensity type of grassland. On the other hand, rough and hill grazings occupy mostly hill and mountain areas with a low level of productivity.

In the U.S.A., Semple (273) made a different grassland classification. Dividing the pastures into (1) tame and (2) natural or native, where the latter is a very extensive pasture, while tame pastures were subdivided as permanent, rotation, temporary and annual and are intensive type of pasture production.

Grassland production systems

Many world regions have livestock systems based on pastures. Some of these are Australia, Belgium, Britain, Holland, Ireland, New Zealand, U.S.A., etc., and in these countries, the economic aspect usually determines the degree of intensity of pasture production. In some regions, land is abundant and it is not the main restriction, while labor or energy may be the limiting factors. In other areas, land is scarce and the production has to be maximized in order to allow the farmer a fair standard of living. In the first case, grazing systems with low energy input are prevalent, while in the second, intensive management, high level of conserved feeds, concentrates, and higher energy inputs are likely (63, 128, 215, 258, 301).

In New Zealand, production is dominated by crop pasture systems based on perennial ryegrass-white clover that gives a fair yield with low N input (24, 196). On the other hand, in some European countries like Holland or England, herbage production is founded on heavy N applications, and their animal production systems rely on a high forage conservation component and on different amounts of concentrate (129, 213, 313, 329).

Several authors have reported that the traditional grassland systems in Europe have proved to be incapable of supporting the intensification required for actual successful dairy farming, mainly because it is not easy to manage a highly variable natural supply of nutrients from grassland with the less variable requirements for milk production (63, 129, 130, 180, 258, 301, 313). The intensification needed can be obtained by different techniques such as increased N applications, irrigation, heavy supplementation, calving date, stocking rate, strip grazing, increased conservation, etc. All these intensification factors raise the exploitation costs but will also increase productivity and possibly the efficiency of the utilization of the pasture (129, 313).

An example of the increased costs of the intensification techniques is given by Reid (261) and by Holmes (128). Comparing pasture herbage, hay, and grass silage for energy and cost efficient, Reid (261) reported that hay gave 7.5 calories of digestible energy for each calorie of fuel energy, compared with 8.2 given by grass silage and 30 to 115 returned by pasture herbage of different types. Holmes (128) gave the relative value of 1 to the cost of producing grazed grass, while the hay cost 2.8 times more and grass silage 5.8 times more than pastured grass. Analyzing the low energy requirement systems, Reid (261) stated that in general, these systems are not sufficient by themselves because the animal does not eat a sufficient amount or the forage is too low in energy concentration to sustain profitable animal output.

<u>Grassland annual crop systems</u>

A different approach in the intensification of pasture systems is by means of annual forage crops. These crops can have three different roles (55, 158, 189): (1) supply feed during periods of initial demand or low pasture production, (2) to provide dry supplements to the feeding program, and (3) to use as "total pasturage," "soilage" or lot feed fodder crops.

The idea of using fodder crops as supplements to intensive pasture production represents an intermediate system between the pure grassland systems and the pure annual or row crop forage systems.

In some areas of Australia, New Zealand and Europe (85, 130, 156, 271, 293, 298, 340), the grazing systems have winter gaps due to cold weather or a summer shortage due to the lack of moisture. To fill the gaps, several winter crops like barley, oats, Italian ryegrass, turnips, cabbages, etc. have been used for pasture or conservation for winter, while for summer improved varieties of grasses and legumes, alfalfa, and sorghum type forages have been used (85, 189, 271, 293, 325).

However, at least in Europe, the huge increase experienced by these grassland-annual crop systems is due to the use of forage corn. The introduction of this crop has implied a huge forage intensification (31, 87, 168, 257, 295). In some countries such as Belgium, Germany or Holland, corn acreage increase has been at the expense of grain crops such as wheat, barley, etc., but in general not through the decrease in grassland area (79, 247, 313, 343). In other areas, corn and annual or biannual crops have substituted for the prairies, at least partially (87).

In all these countries with a limited farm size, corn as a high yielding crop offers the possibility of increasing feed production and thereby animal production per ha and thereby increasing the final profit per ha (168, 215, 300, 313). Corn is considered, nevertheless, an expensive crop with an unstable yield, compared with pastures (257, 279). However, several publications showed that the cost of the unit of metabolizable energy of forage maize for silage is simliar or lower than the cost of the unit provided by the grass silage (128, 279). Similar results have been shown in Galicia, depending on the area of the region (177).

On the other hand, although in England corn is grown at the limit of its physiological adaptation, the annual yield fluctuations with coefficients of variation (CV) of 20%, are very similar to that of perennial ryegrass (CV = 17%) (279). Analogous results have been obtained in western France (257). The next step in the intensification process implies the use of cropping systems where the grasslands represent a small percentage of the total area or where the annual or biannual crops are dominant. This subject will be discussed in the next section.

Before finishing this brief analysis of some row crop-grassland systems, it has to be clear that these strategies are only possible where row crops can be cultivated. It is well-known that in many areas pasturage is the only forage which can be grown profitably due to soil type, topography, rainfall, climate, etc. (63, 109, 258).

Cropping systems based on annual plants

In previous sections, different degrees of forage production intensification have been presented. The last step in this process is the use of chiefly annual or biannual crops. However, these plants can differ depending on the area of the world. For a particular farm, the crops seeded depend on a variety of factors such as climate, soil, water, kind of product, etc. and mainly on the cropping system practiced. This term has been defined (7) as cropping patterns used on a farm and their interactions with farm resources, other farm enterprises and available technology which determines their makeup.

However, as was discussed in the last sections, the farming systems in a region are not fixed forever. It has been the general pattern of the world agriculture to try to substitute and change the crops and the cropping systems when circumstances changed (7). This evolution has been done in the forage systems as well as in the grain production systems. Most of the time the main factor that causes cropping systems to change is the economy, mainly in developed countries. As farming costs increase, alternatives need to be developed in order to increase productivity and catch up with costs (313) or in order to reduce expenses. Modern technology has allowed the substitution of animal for machine power and modern machinery has simplified the arable systems, reduced the area of some crops, such as oats, and subsequently increase of the others (4, 110, 129).

Implicit in the idea of change is the aspect of increasing productivity of the land, to get the most production and benefits of the land. Two of the subjects that have been receiving more attention in this land productivity race are the intensified grassland production systems, already examined, and the multiple cropping systems with monocropping. In this direction, Papendick et al. (237) wrote that "the gains in production per unit area with monoculture cropping with a single harvest per season have not been impressive in recent years. . . and more promising for many is to increase food output with the development and application of new technology for multiple cropping systems."

Multiple cropping   Multiple cropping has been defined by Andrews and Kassan (7) as the intensification of cropping in time and space dimensions by growing two or more crops on the same field in a year. Different aspects of multiple cropping have been reviewed in the publication Multiple Cropping (237).

Among the multiple cropping systems, double cropping (growing two crops in a sequence) is maybe the most extended in developed or semi-developed areas in temperate climates. In this review, more attention will be given to this latter system, because it is directly related to the main subject of this dissertation. However, it should be commented that in Galicia different types of intercropping (growing two or more crops simultaneously on the same field), with a forage component, are still practiced. The most important are: corn → Italian ryegrass, corn → *Avena* ssp, corn → turnips (176).

Double cropping systems   Many double cropping systems are practiced around the world, depending on geographical location, climate restraints, economical situation, etc. (176, 237, 257). In this thesis, the European and U.S. systems are going to be emphasized because of their close similarities with Galician crop rotations.

Double cropping systems can be divided into three different sections according to their final product:

(a) Double cropping for forage production;

(b) Double cropping for forage and grain production; and

(c) Double cropping for grain production.

Types a and b are the most interesting in this dissertation, but mainly a, because this is the kind of rotation used in the experimental part of this thesis.

From now on, all the productions cited in this dissertation will be expressed on a dry matter basis.

European systems Double cropping is practiced in areas where the winter climate or the summer rainfall allow the system. In Europe, these conditions are mainly given in the northern part of the southern European countries and in some areas of central and western part of the continent. To be precise, most of the reports on double cropping systems come from the countries bordering the Atlantic Ocean. In these areas, the winters are generally mild and humid and the summers drier with warm temperatures.

In southern Europe, Spain and Italy, double cropping is potentially feasible, but the crops need to be irrigated. In this case, they normally grow cash crops but not forages (21, 219). The same can happen in other areas.

There are, also, different reports from eastern European countries in which double cropping systems have been studied (239, 317). However, for obvious language translation difficulties, only very brief references will be made to them. When examining the European crop rotations with some kind of double cropping forage component, it is possible in general to distinguish the double crop annual rotation dedicated entirely to the production of forage, the annual crop rotation with a "catch crop," and the pluriannual rotation with a "break crop" for forage. The idea of "catch crops" is a quick-growing crop between two main crops, and the "break crop" is a plant sown to break the monoculture of a certain crop. These terms are used in several countries.

The next pages will be dedicated to the examination of several of these European cropping systems.

Galicia Corn is the most important crop of the region and most rotations are corn based (22, 176). The most extended rotations for forage and for grain-forage production are:

corn → oats corn → Italian ryegrass corn → rye	annual
corn or potatoes → wheat or rye → turnips or rye (for forage)	biannual

The seeding time for corn varies from mid-April to end of May depending on the location and the weather conditions, and harvest is normally by mid-October. If the corn is for silage, it is harvested by the end of September.

The yield of the winter crops depends mainly on the seeding time; early fall seeding is necessary to obtain large forage yields. The harvest time for these crops differs. Rye is very well-adapted to the system and usually comes first, and its heading time is about 20 March, which gives adequate time to prepare the land for corn. Oats and Italian ryegrass can be harvested 3-4 weeks later, but in this case, there is a shorter time for preparation for corn seeding.

In the biannual crop rotations, corn is planted and harvested as it is in the annual rotations. After corn, two main crops are seeded depending on the locations, winter wheat or winter rye, which are harvested around the beginning of July for rye and end of July for wheat. Then, after preparing the land and after any rain in August, turnips are seeded. This crop provides forage in winter, January-February, and allows adequate time to get ready to plant corn again.

Another rotation that is becoming popular is temporary prairies → corn or potatoes. Temporary meadows need to be reseeded every 4-7 years, and the normal time to plow them under is in spring, while the seeding time is at fall. A lot of farmers plant corn or potatoes during this summer period. By doing this, they intensify production and also after a row crop the land is better prepared for the next prairie sowing.

In Galicia, very few data have been published about double cropping for forages. Garcia (98) reported that corn-Italian ryegrass rotation can produce an average yield of 13-16 t/ha, while the rotation corn-oats corn produced 1-2 t/ha more. Lloveras (177) estimated that the yields of the rotation of corn with rye, oats or Italian ryegrass could be about 14-18 t/ha. Of this production, 10-13 t correspond to corn and the rest to the annual crop following corn.

France Where these intensive double cropping systems for the production of forages have been more extensively adapted and studied is in the upper mid-west Atlantic coast of France (256, 257). This area, in particular the region called "Bretagne," has had a great agricultural evolution in the last 25-30 years and agricultural production has been mainly directed to the production of forages throughout the double cropping intensive rotation, corn → Italian ryegrass. They also follow other systems which are not as intensive that include wheat for forage, permanent prairies, kale, forage rape etc. with everything directed mainly to milk production (253). In that area, the farm size is also quite small compared with the U.S.A. The average farm size is around 15 ha, with most between 10-50 ha.

Corn yields in West France are inconsistent because corn is at the limit of its growing area, and it is very sensitive to climate variability. Their normal yields are about 11.5-13.0 t/ha or less of dry matter, but they can vary from 70% up to 140% of that average yield from one year to another. Yield depends mainly on planting date. Delays of seeding because of previous crop harvest (Italian ryegrass) are detrimental to corn yields (256, 257).

Italian ryegrass is the crop that normally follows corn, is seeded after corn and harvested in April or May. Yields change a lot depending on the date of harvesting. April harvest produces 2.7-4.9 t/ha of dry matter, while in May they give about 5.5-8 t/ha. The later harvest delays corn seeding and consequently there is a reduction in the next corn yields (256). Another system followed with Italian ryegrass is what they called Italian ryegrass 18 months. The ryegrass is seeded after corn remains on the field for about 18 months. In both systems, ryegrass production is based on heavy N applications. The recommendations for Italian ryegrass double cropped with corn are 100-150 kg N/ha and for 18 month ryegrass 200-400 kg N/ha (144, 253). Such amounts of N are not normally used in Galicia where double crops get at most 80-90 kg N/ha, although in some farms heavy amounts of slurry are applied.

Those intensive cropping systems are very productive but also very fragile and stressing. Currently there is some evolution in favor of the permanent or temporary pastures in order to find certain equilibrium between production and intensity (257).

Economical studies in this region (215) have shown that the benefit per hectare is proportional to the milk production per ha, and this is directly related to the intensification. The most intensive producing farms have a greater percentage of the area in corn-ryegrass rotation, while the most extensive farms are based on permanent pastures. They also concluded that since the intensive systems are high labor demanding, more acreage is going to be dedicated to pastures.

<u>Britain</u> Several cropping systems with a forage component have been reported in Great Britain. In this country, the farmers have promoted the concept of "ley farming" in which grassland was grown for 3-4 years and then dedicated to cereal or root crops to take advantage of the improved soil fertility (166, 180). However, this kind of rotation has led to a more specialized and intensive cereal production, mainly

barley. The monoculture of cereals in humid conditions normally leads to severe soil diseases. For this reason, some kind of "break crop" has to be seeded every several years. Some "break crop" plants are broadbeans, rape, cabbages, corn, etc. In some of these cases, double cropping is practiced because, after harvesting cereal, a winter crop of rape, turnips, etc. for forage can be planted. However, the most common "double cropped" practice in Great Britain is spring cereal → catch crop. This system is followed mainly in the south. After the spring barley crop, quick growing and inexpensive crops are grown for forage. These are normally cruciferous (turnips, forage rape, fodder radish, etc.), which are sown around early August and provide forage, particularly for sheep, during the fall and early winter (180, 277). The catch crops can produce from 2 to 4 t/ha.

Some trials have been conducted with true double cropping systems based on winter rye (278). In these experiments, rye was followed in June by corn, sunflower or Italian ryegrass. The best yields were obtained by the rye-sunflower sequence which produced 15.2 t/ha and 8.9 t/ha of digestible organic matter. They concluded that higher yields have to be obtained for such double cropping systems to be attractive.

<u>Belgium</u> Several studies on the intensive cropping systems in this country have been published (27, 247, 312). Economic studies showed that for dairy farms it is of great importance to increase production of milk/ha. A greater production raise can be achieved by intensification of the grassland production and by means of annual crops. In this country, in the last twenty years corn acreage has increased from

0% to 11.0%, while prairies have decreased from 89.7% to 85.8%. All other crops have decreased to leave room for corn (27, 168).

Different double crops have been tested after corn and, in Belgium conditions, the best plant seems to be rye. Corn forage yields are about 11 t/ha, while the corn-rye rotation produced about 13-14 t/ha (312). It looks like this area is at the limit of corn double cropped, and for this reason, the yields of double cropping are not very superior to monocropped corn. This idea is supported by the fact that only 8% of the tilled land is double cropped (247). According to Pieters (247), the main crops used in double cropping are in descending order, turnips, forage rape and rye.

The general conclusion is that acreage is usually the limiting factor for dairy farms and that double cropping can increase yields.

<u>Other countries</u> In general, in several countries, some catch crop systems are practiced or have been tested. The basic idea is that the second crop should be planted as soon as possible in order to produce an economic yield, and that irrigation can increase the yields of these catch crops.

In Ireland, some experiments have been conducted to study the productivity of several catch crops (rape, forage turnips, ryegrass and rape) after spring cereals. The yields obtained were from 3.40 to 4.5 t/ha for turnips sown in early August and harvested 3 months later. Other study obtained 6.5 t/ha of dry matter from rye sown in October and harvested in June (155).

Some studies show that catch cropping is also practiced in

Switzerland. They sow oats, oats and vetch, and oats and forage rape, generally after cereal, at the beginning of August and the best yields obtained at the beginning of October were about 4 t/ha (311). Other countries in which catch crops or double cropping have been reported include Czechoslovakia, Denmark, Germany, Italy, Romania, Russia, Yugoslavia, etc. (108, 126, 183, 201, 239, 317).

United States systems The general idea about multiple cropping in the United States is that in order to obtain acceptable yields for the main summer crops (corn, sorghum, cotton, etc.), the previous crop has to be removed early enough that recommended planting dates can be followed (173, 224). As it has been commented, this is the same principle that is applied in the corn → Italian ryegrass system in Europe. In many double cropping systems, one of the crops, normally a small grain, is used for forage because this facilitates better seeding time for the main crop.

In the U.S., the development of no-till planting techniques has contributed to the success of double cropping by enabling a second crop to be established with the least delay. Double cropping has proven successful under the longer growing seasons in the southeastern U.S. but in recent years has extended to other parts of the country (173). Comparing double cropping in Europe and in the U.S., the system appears here to be a recent discovery, while in Galicia, for example, where the population pressure has been always higher, these systems have been practiced for many years. On the other hand, in the U.S., the larger farm size, the usually better land structure and the research done in different areas of the country provides farmers with a more mechanized and modern technology to master the double cropping systems.

Double cropping for grain production An excellent review of the double cropping in the U.S. can be found in Multiple Cropping (237). It is the purpose here to present some reports to show the variety of possible double cropping combinations, some of them already a common practice, others still in the research phase.

Corn and sorghum for grain or silage and soybeans for grain have been successfully double crop planted in June following winter barley in eastern Virginia (39).

Triplett (309) reported that a good weed control is necessary, and it is used extensively to produce double cropped soybeans after wheat in Ohio.

In Oklahoma (56), soybeans after wheat is a normal practice, and double cropped resulted in more total grain production and effective use of annual precipitation when compared to monocropped wheat or soybeans.

Lewis and Phillips (173), in their review of the double cropping in the eastern United States, conclude that soybeans after wheat or barley is the most successful system in that area.

Other combinations have been or are being investigated. In the coastal plain of southeastern U.S., double cropped corn has been tried (328). They found that it might be a viable option if the second crop were taken as forage rather than as grain. The best economic combination was an early hybrid for grain followed by a late maturing hybrid.

In Wisconsin (222), they have tried to develop some management practices in order to recommend the system of peas for canning followed by sweet corn.

Smith and Varvil (282) discouraged the sequence cotton → wheat for the northern U.S. cotton belt. Seed cotton yields in double cropping compared with single cropping were reduced by 35 to 50% with early maturing genotype and 50-65% with a full season variety.

Wheat followed by sunflower has been reported in Virginia (212).

Some of these combinations would not be possible in Galicia for two reasons: (a) the growing season would be too short and (b) lack of water during the summer. In a normal year, it would be very difficult to get a second crop without irrigation.

Double cropping for forage or for forage-grain production

It has been commented earlier that some double cropped sequences are only possible if one of the crops is used for forage. The reason is because otherwise the growing season is not long enough to allow two grain crops at least without some economical cost. For example, Nelson et al. (224) in Georgia found that no-till corn and grain sorghum produced higher yields when planted earlier after small grain forage than when planted late after small grains for grain. In other related work (225), corn forage production was evaluated in double cropping systems following wheat and barley. They also reported reduced corn forage yields for mid-June plantings after small grains than for April date of planting. They concluded that there is a high forage potential for double cropped no-till corn planted early in mid-April in southeast U.S. Corn yields for early plantings were about 13 t/ha of dry matter.

Also, in the southeast of U.S. (96), several multicropping systems were compared. The study showed that small grains for forage followed by sorghum forage followed by a sorghum forage ratoon gave an average yield of 22 t/ha of dry matter. This system gave greater dry matter production as compared to 16.4 and 19.7 t/ha for systems with sudax and corn forage, respectively.

Studying the use of sunflower in double cropping no-till systems, Sheaffer et al. (276) in Maryland planted sunflower, corn and sorghum into stubble barley. These crops were seeded at the beginning of July and harvested after mid-September after the sunflower varieties reached flowering. They found that sunflower can be competitive with corn in terms of dry matter production (average sunflower yields were 7.50 t/ha and corn yielded 6.70 t/ha), but the low forage quality is a limiting factor in the potential use of this crop.

According to Murdock and Wells (218), double cropping has become a popular and economical practice in Kentucky, but very little research had been done upon which to base fertility and management conditions. They reported that double cropped barley or oats for forage followed by corn produced 26% more dry matter than corn alone (20.45 t/ha vs. 16.43 t/ha). This experiment was managed for maximum corn production. They also found that yields of the single cropped corn were slightly greater than that of double cropped, and the reason could be that the small grains removed moisture available for the next corn crop. The small grains also removed large amounts of minerals, particularly K.

In a research conducted in Minnesota (57) for maximum biomass production, they compared winter rye double cropped with corn with monocropped corn, sorghum and sudangrass. Winter rye was seeded at the beginning of October and harvested in mid-June at the hard dough stage, then a double cropped corn was seeded. This late corn was harvested by the end of September. On the other hand, monocropped corn was seeded by mid-May and harvested about mid-October. The yields were 25.9 t/ha on the double cropped system and 18.8 t/ha for the best corn monocropped. They concluded that since the costs and risks of producing successfully two crops would be an important consideration, monocropped corn would be preferred over corn → rye on biomass production systems in Minnesota.

At Iowa State University, Helsel and Wedin (123) compared several combinations of crops in monocropping and double cropping systems for dry matter yield, nutritive composition and combustible energy. They found that the average dry matter yields of main crops were greater in the single cropped system than in the double crop system, where the main crop dry matter yields declined with the later dates of planting. However, some crops (sorghum x sudangrass hybrid, forage sorghum, pearl millet, sunflowers, soybeans) produced comparable yields in a rye-double cropped system and in single systems. The highest yields of about 18-20 t/ha were obtained on corn for grain, and corn for silage in the monocropped systems and forage sorghum and sorghum x sudangrass hybrid in both the monocropped and rye double cropped systems. They concluded that there is a potential for increasing harvestable dry matter in double cropping systems in the northcentral United States, particularly if a small grain is harvested early for forage is the first crop in the double cropping system.

In New Mexico, where the climate is mild enough for small grain forage between summer crops, some research has been reported (95) on the forage yield potential of multiple cropping systems. Three different crop rotations that represent three different cropping intensities were compared: (a) corn, (b) corn → barley double cropping, and (c) corn → sterile wheat → barley (2 years). The results show that the annual yield increased with increasing cropping intensity; corn (monocropped) produced 15.23 t/ha, corn → sterile wheat → barley (3 crops in two years) output 17.13 t/ha, and finally corn → barley (double cropped) yielded 26.62 t/ha. The results show that it may be economically feasible to obtain two good forage crops in one year since forage or silage crops can be removed earlier than grain crops.

In Minnesota, there is a research going on (185) where they study the feasibility of producing two forage crops planted and harvested in the same year. They investigate the combination of spring barley, seeded as early as possible, with sudangrass, Italian ryegrass, soybeans, forage rape, cowpeas, turnips and the weed kochia (*Kochia scoparia*) as potential second crop for grazing from August to October.

General reflections on forage cropping systems After reviewing several European and U.S. cropping systems, it is clear that there is no general pattern and that they differ widely. The cropping systems followed in a particular area are the result of physical, economic and sociological factors and to find the most appropriate is a matter that needs specific research.

Annual Crop Species

The crops reviewed in this section are the ones that have been grown in the experimental part of this dissertation. This includes the plants cultivated in the crop rotation experiment as well as the crops compared for summer forage production.

The species that are going to be examined are corn (*Zea mays* L.), sudangrass (*Sorghum bicolor* (L.) Moench var sudanese), sorghum x sudangrass (*Sorghum bicolor* (L.) Moench), sunflower (*Helianthus annuus* L.), as a summer crop and forage rape (*Brassica rapus* L.), oats (*Avena strigosa* Schreb), rye (*Secale cereale* L.) and vetch (*Vicia villosa* Roth) as winter crops. Italian ryegrass (*Lolium multiflorum* Lam) and alfalfa (*Medicago sativa* L.), used as a summer crop, will be reviewed in the grassland systems section.

Corn

It is the third most important cereal in the world, following wheat and rice. Corn is included in the group of tropical grasses having a C4 cycle for CO_2 fixation, and its production and crop growth rate are among the highest of all commonly grown crop species. Corn is widely used for both grain and silage.

The importance of this crop in the U.S. is well-known. In Europe, with a different climatological pattern than the U.S. midwest, the crop has had an enormous expansion in the last 15 years. Now it is also grown in the west-central areas of the continent (France, Belgium, Holland, Germany, southern England) near the limit of its physiological adaptation and it is grown mainly for forage. This huge increase of corn in the old continent is chiefly due to the development of new short season hybrids well-adapted to the cold areas and short growing seasons.

The threshold temperature for corn germination and growth is about 10 C, higher temperatures decrease the length of the growth, and the maximum rate of photosynthesis occurs at 30 to 33 C (48, 274). Practically no corn is grown where the mean summer temperature is less than 19 C or where the average night temperatures during summer months fall much below 13 C (274). However, at present, corn is also grown in areas with a seasonal mean temperature of approximately 15.5 C (31).

Water availability is also an important criterion in corn production. To obtain maximum biological yield, the crop must have sufficient water available throughout its whole growth period, but water stress is more serious at certain periods of phenological development. Water stress during flowering reduced grain yield by 50%, while stress during the period of ear growth reduced grain yield by 21% (69).

The normal water requirements during the seasons can range from 25 to 650 mm, depending on the climatic area, type of hybrid, etc.

Corn is a very thoroughly studied plant and is the base for many different cropping systems; consequently, a large number of research papers have been published about many aspects of the crop. In this review, only selected papers are going to be discussed, and most of them about corn for silage.

Production, management and fertilization Potential yields can only be reached with agronomic practices such as weed and pest control, optimum fertilization and plant rates, selected hybrids, optimum planting dates, etc. (31, 48, 58, 61, 142, 165, 206). However, all these production factors are related to each other, and in silage production, the complexity increases because the quality component is as important as the quantity. It is practically impossible to separate all these factors, one by one, but for simplicity a division by regions will be used.

Galician situation Most of the corn area of Galicia is seeded with open pollinated varieties, and no more than 25% of this area is planted with hybrids. The main reason, apart from the economical point of view, is because until recently there have been very few short season hybrids well-adapted to the area (205). Due to cold and rainy conditions during and after planting time, corn varieties in northwestern Spain must have early vigor for growing quickly in the first vegetative stages and for competing adequately with weeds. Early vigor and emergence in cold wet soils are characteristics commonly found in the local varieties because of a long period of adaptation. These local varieties have generally flint endosperm. Recommended varieties of corn for most parts of Galicia are on the 300-400 F.A.O. cycles. Although in the northern areas it is possible to plant 500-600 cycles, in the highest areas normally an F.A.O. 200 should be used.

Most of the corn research in Galicia has been done with corn for grain, but there are also data with corn forage. The recommended plant density for silage production is about 100,000 plants/ha for early hybrids and about 90,000 for medium hybrids. Although these rates should be reduced about 25% in very dry areas (206). A summary of yields obtained on research experiments has been reported by Moreno and Losada (207). Analyzing data from 1969 to 1980 in different locations of the region, dry matter (DM) yields ranged from 11 to 18.3 t/ha in rainfed conditions and from 15 to 19.3 t/ha when corn was irrigated. They concluded that in normal conditions it is very easy to obtain 11-12 t/ha in rainfed conditions and 14 to 15 t/ha with irrigation.

European and U.S. results Many research papers have been published about the relationship between plant density, total yield, ear/stove relationship and crop quality and their interactions with genotype and environment. A corn silage production guide has been published in France (142). Yields of 10-12 t/ha should be expected, even in bad years. Results reported for early varieties show yields between 12.5 and 13.5 t/ha with a dry matter content of 28.5 to 31.8%, and the ratio of ear/total plant of 57.7% to 61.1%. The medium-early varieties grown further south gave a little higher yields, 14.1 to 15.1 t/ha, with a DM content of about 40%, and the ear represented about 63% of the plant total dry matter. The medium-late varieties grown in the southern part of the country produced about 15.0 to 17.4 t/ha, with a dry matter content of 40.5 to 44.8% and the ears were about 60% of the total DM weight of the plant.

Other study with early varieties showed a 1.4 t/ha increase in yield where the density went from 76,000 to 115,000 plant/ha, although the proportion ear/total plant decreased from 66.9 to 63.4%. In this work, they obtained the normal trend in corn studies, that is, dry matter yield generally increases with increasing population up to certain densities but the proportion of ears decreased (8, 9). For France, they recommend for very early varieties densities from 90,000 to 110,000 plants/ha, for early varieties 75,000 to 90,000 plants/ha, for medium-early varieties 65,000 to 80,000, and for late varieties 55,000 to 70,000 plants/ha.

As it is well-known, the climatic conditions are by far the most important factors affecting forage corn production and composition. In France, with good growing conditions, early varieties harvested at satisfactory dry matter content of 30 to 35% give production levels of 12-14 t/ha, of which 60 to 65% is in the ear and husk (8, 9). In the northwest part of the country, corn yields are very unstable although very productive. Mean yields are about 11.5 to 12.9 t/ha, with a year-to-year oscillation going from 60% to 140% of this production. However, these variations are still lower than those obtained for the winter grasses (257). It is well-known that the influence of date of sowing on the production and composition of forage corn can be very variable, depending on the earliness of the variety and environmental conditions. In general, later sowing gives poorer results than earlier sowing, both in terms of dry matter production and percentage of ear in the plant (8). Some French data with early varieties show that with early sowing (mid-end April) yields were about 0.5 to 3 t/ha higher than with late sowing (mid-end May) (8, 142).

In Britain, which is near the northern limit for growth of corn, Bunting (30) reported that for the standard variety INRA 200, the grain yield/unit area was maximal at densities of 8 to 10 plants/m^2, and that differences in average yield at densities ranging from 6 to 14 plants/m^2 were less than 6%. However, other early varieties reached maximum yield at lower densities (6 to 8 plants/m^2). In a different study in England, Iremiren and Milbourn (141) obtained higher DM yields at 17 plants/m^2. Over the range of 11 to 17 plants/m^2, the increase in yield ranged from 1 to 1.6 t/ha. On the other hand, the whole crop dry matter percentage was about 23-28%. Total dry matter yields reported by Phipps and Weller (246) for short season hybrids were about 11.3 to 13.2 t/ha, with an ear content of around 55 to 63%, depending on the variety.

In Quebec (Canada) in a four year study, Genest and Dionne (100) obtained maximum dry matter yields with 133,000 plants/ha. The mean production was 12.25 t/ha, with the best hybrid yielding 13.50 t/ha. Logically, at higher densities the contribution of ears to the total dry matter production decreased. The mean percentage of ears/total DM was about 45%.

In the U.S., plant densities and crop yields vary depending on the location. In Iowa, the normal plant population ranged between 45,000 and 60,000 plants/ha when planted for silage (294). Bryant and Blaser (26) in Virginia compared several plant populations and hybrids. They found that 99,000 plants/ha gave the highest yields, but this yield was not significantly different than with 50,000 or 67,000 plants/ha. The production averaged 11.8 t/ha for early hybrid and 12.4 t/ha for late hybrids having an ear content 68.6% and 57.5%, respectively. The dry matter content was about 55% for the early hybrid and around 50% for the late variety. In Georgia, Cummins and Dobson (61) reported that yields increased significantly as populations increased from 49,000, 68,000, and 86,000 plants/ha (10.5, 11.6 to 12.3 t/ha). As populations increased, ear content decreased from 55 to 45% and stalk content from 27 to 32 percent. In a different location, dry matter yields with a somewhat lower plant population went from 17.7 t/ha to 26.0 t/ha. Working with similar densities, Cummins (58) stated that higher plant populations never reduced yields compared to lower populations, so even in the case of droughty soils, higher populations could be planted to take advantage of seasons with desirable rainfall distribution.

Similar results were reported by Deloughery and Crookston (66). They planted corn at 25,000, 50,000, 100,000 and 200,000 plants/ha and showed that as plant density increases, Harvest Index decreases because less dry matter goes to the grain. At normal populations, 50,000 plants/ha, Harvest Index was about 0.40. However, from the standpoint of total biomass production, there was little difference between 50,000, 100,000 and 200,000 plants/ha. They did not mention the quality of the forage obtained.

In a study reported from Wisconsin (307), plant populations of 60,000 plants/ha gave similar yields to those of 96,000 plants/ha (15.68

t/ha), although the grain content was decreased.

In Nebraska, Perry and Compton (244), working with three corn hybrids for silage under irrigated conditions, obtained mean yields of 23.31 t/ha for 1973, and 19.72 t/ha for 1974. Ear dry matter production was 12.02 and 10.61 t/ha, respectively. The largest total yield obtained was 26.51 t/ha.

In Iowa, Helsel and Wedin (123), working with corn silage, reported dry matter yields of 15.44 t/ha for 1974, 22.81 t/ha for 1975, and 16.51 t/ha for 1976. The density was about 64,000 plants/ha.

Under good growth conditions, corn hybrids can reach, as it has been shown, very high yields. However, it requires a fertile soil or alternatively high levels of applied fertilizer. Maximum crop growth occurs at pH between 6 and 7, but corn is considered as a relatively tolerant crop to toxic concentrations of Al and Mn (165).

According to Larson and Hanway (165), corn producing 10 mt/ha of grain contains about 200 kg of N, 84 kg of P_2O_5 and 230 kg of K_2O for the grain plus stover. Crop fertilization will, of course, differ depending on the previous crops, expected yields, soil test, etc. However, the rates recommended in practice in Europe are about 120-160 kg N/ha, 100 to 150 kg P_2O_5/ha and 100-150 kg K_2O/ha (8, 140).

Crop quality For most forages, there is an inverse relationship between maturity and quality and between total yield and quality. As the plant gets older and the production increases, the forage quality declines. This is not the case with corn silage.

It is well-known that corn dry matter production increases up to its physiological maturity (9, 114, 295). Most extension publications recommend to harvest corn for silage at this stage because this is the point at which maximum dry weight of grain has been reached (142, 294). However, it is very interesting to examine the changes occurring in the plant which make the crop maintain high forage quality even at physiological maturity. Another subject widely investigated (9, 26, 61, 100, 246) is the effect of grain content on silage quality and, consequently, the relationship between plant density and crop silage quality.

The development of the plant from the seedling stage to maturity is a series of morphological and physiological changes. At early stages, the whole plant is stover, but as the plant reaches maturity, the ear becomes the most important part for determining forage quality and represents about 45-65% of the total plant yield, depending on the density (114). After flowering, the yield of nonreproductive parts continues to increase, but grain filling, at least during the last weeks, occurs partially at the expense of dry mass (mainly carbohydrates) stored in the stover, husks and shanks (295). This redistribution of nutrients logically brings about changes in the quality of the different plant parts, because the digestibility of the nonstructural carbohydrates is almost 100%, while the digestibility of the structural material (cell wall constituents) is much lower (244, 295, 307). In Holland, Struick (295) obtained what is, more or less, the typical digestibility evolution pattern, at least in Northern Europe. Cell-wall content increases until flowering remains constant for a time after this stage and then decreases during later stages of grain filling. The digestibility of the organic matter declines rapidly in the pre-silking period (from about 90% to around 73%) and then increases slightly. This decline is compensated for by the increase in ear content, which causes the relative content of the less digestible cell walls to decrease. He also commented on the differences between the changes in digestibility of the crop during the season in tropical and in cool areas. In tropical climates, digestibility may increase considerably after flowering. The decline during stem elongation is great, because high temperatures stimulate lignification. However, high irradiance and full ear development will guarantee a strong "dilution" of cell walls. In the cloudy autumn climate of northwest Europe, a decrease in digestibility is common. Digestibility of the stalk is already high because of high cell-wall quality, and the increase in starch content represented by the grain cannot always compensate for the decrease in cell-wall digestibility because starch is partly formed from sucrose which had been stored temporarily elsewhere in the plant.

An excellent example of quality changes in forage quality of corn is the paper written by Perry and Compton in Nebraska (244). They grew various hybrids and measured several parameters after flowering. They found a continuous increase in total dry matter production from 9 to 58 days after flowering. Most of this production increment was due to the ear that went from 0.30 t/ha to 12.02 t/ha, while the leaf dry matter did not change very much and the stalk dry matter production normally decreased 1 t/ha. On the other hand, crude protein content of leaves continuously decreased from about 16% to 7.5% and the ears decreased from 15.5% to 7.5% and then remained constant. Stalk crude protein content was very constant at about 4 to 5%. The same study also reported the IVDMD (in vitro dry matter digestibility) values. For the ears, the values were high, as expected. The values changed from about 88% in young ears to 80 to 84% in mature ones. The IVDMD values for the leaves decreased a little from a range of 65 to 68% to 56 to 62%, while the stalks decreased from a range of 56 to 62% down to 44 to 50%. They concluded that total plant IVDMD yields increased at each harvest, and that 47% to 61% and 60 to 69% of the total plant IVDMD yield was contributed by the ear portion on the antepenultimate and last harvests, respectively. Thus, ears contribute much of the digestible material in corn silage, but a considerable amount also comes from the digestible portions of leaves and stalks.

A similar type of research has been conducted in Wisconsin by Tourbier and Rohweder (307). They reported that whole plant and ear dry matter yields significantly increased with successive harvests and were greatest at physiological maturity. In their study, the stage of maturity at which corn was harvested had a significant influence on silage quality, because neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations declined with each advancing stage of maturity and were both lowest at physiological maturity. NDF values went from 53.9 to 59.4% down to 42.9 to 43.9% and ADF from 28.6 to 31.2% at early dough to 20.9 to 23.1% at physiological maturity. Crude protein contents also declined from a range of 9.0 to 10.7% to 8.1 to 9.0%, while the whole plant dry matter increased from about 24.7% to 47.0%, and the ear/stover ratio climbed from a range of 34.4 to 37.0% to 56.8 to 58.4%. The total dry matter yields increased from 12.66 t/ha to 18.16 t/ha. They concluded that according to the values obtained, physiological maturity is the best stage of corn development to harvest corn for silage. However, where corn reached this stage, the dry matter contents were 43 to 49%, and at that level, proper fermentation cannot be assured and feed quality might be sacrificed.

In a different part of their paper, they referred to studies in Wisconsin which showed that increasing amounts of N fertilizer increased the concentration of total N. Other authors (9, 100) have shown that the increase in quality of the total crop, as crop yield quality increase, measured by the IVDMD, ADF, NDF etc., is mainly due to the contribution of the ear content. For this reason, the grain content of the silage is frequently used as a criterion of quality (203, 234). Other authors (97) stated that without precise variety knowledge, it is normally recommended for corn silage to choose the varieties with high grain content.

The importance given to the grain content in corn silage is the reason why most of the papers reported in the previous section about crop production and plant density calculated the ear/stover ratio (246). However, in some northern European countries, working with high densities and short season hybrids, the increase in ear content is not always enough to compensate for the decreased quality of the stover (246) and breeding programs are conducted for higher stover quality and density tolerant varieties (245).

Corn forage quality values have been reported in many different papers. Cummins and Dobson (61) obtained the following IVDMD values: for ears 71.0 to 80.5%, for leaves 59.1 to 63.8%, for stalks 50.5 to 60.8%, and for the whole plant 62.9 to 72.2%. In their experiment, they used hybrids with differing maturity, row spacings, and plant populations. In a different publication, Cummins (59) studied the influence of irrigation and maturity on corn silage yield and composition, and found plant IVDMD values were the same for late milk, dough and late dough stages (55%).

Other reported IVDMD values in the U.S. (322) are the following: grain, 99.4%; cob, 69.6 to 64.3%; husk, 87.6 to 82.4%; leaf, 84.6 to 80.3%; and stalk, 72.4 to 66.1%.

In Canada, Genest and Dionne (100) obtained mean whole plant IVDMD values of 63.9 to 68.7%, with a maximum digestibility of 73.3% and a minimum of 55.2%. Also in that country, Daynard and Hunter (65), with a harvest date study and with a mean of four hybrids, reported the following values: whole plant, 70.4 to 71.2%; stover, 54.2 to 61.8%; husks, 66.0 to 74.0; cobs, 49.9 to 57.3%; and grain, 83.4 to 86.3%. Except for grain, the higher values corresponded to harvests in early September and lower values to late September.

In France, some quality parameters for several hybrids have been reported (97). The organic matter digestibilities of the whole plant ranged from 71% for the worst hybrid to 75% for the best. The "in vitro" organic matter digestibility (IVOMD) for stalks varied between 44 and 66%, while the crude protein (CP) contents went from 5.5 to 11.1%.

Andrieu (9), using silage corn with different DM contents, reported IVOMD values of 68.4±1.6 for relatively early harvest to 71.6±2.0 for forages with 30 to 35% DM. The mean value of the whole series was about 70%.

In Britain, Phipps and Weller (246), working with very early varieties, found the following IVOMD values: the whole crop declined from about 78% in late August to 70% at the beginning of October, while the ear went from 85% to 77%. In the same experiment, the ADF contents for the whole crop were about 21% for early harvest and 23% for October harvest. For the ear, ADF changed from about 13% to 11%, the values for the stem increased from 23.5% to about 36%, and the leaves also increased their ADF content from 26.8% to 36.3%. In a different paper, Phipps (245) presented similar values when using low plant densities and very early hybrids. The IVOMDs varied from 72 to 77%. These same varieties had ADF contents of about 23.6% and NDFs of 43.5%.

Sudangrass and sorghum x sudangrass hybrids

These species belong to the genus *Sorghum*, which has C_4 photosynthesis and is best adapted to warm or hot regions. These *Sorghum* forage species are notable for their high yield, their capacity of regrowth and their efficient use of water. Compared with corn, sudangrass and sorghum x sudangrass species need higher temperatures for their normal physiological development. The most favorable temperature for the growth of the plants is about 33 to 37 C (5, 187) and normally no Sorghum is grown at temperatures below 15 C. However, some varietal differences have been found (172), and some varieties have germinated in controlled conditions at 8 to 10 C, although temperatures of 8 C during 15 days at seedling stage were lethal to most of the plants (172). Compared with corn, several authors recommend Sorghum species to be planted 1 to 3 weeks later (85, 112). Normally Sorghum species are considered sensitive to low temperatures which delay germination, seedling emergence, thus increasing the risks of seed decay and leaving seedlings vulnerable to soil-borne diseases (187). During a period of drought, the plants remain practically dormant but resume growth as soon as there is sufficient rain to wet the soil. Compared with corn, the leaves and stalks of sorghum wilt and dry more slowly, and thereby enable plants to withstand drought longer (187).

The main interest of forage Sorghum species, at least in the U.S., is as a supplementary or emergency forage. These plants can provide supplies of quality forage during mid-summer, when the perennial cool-season forages are less productive (112, 187). Sudangrass is considered to have a good regrowth, and it is generally used for grazing and hay whereas the sorghum x sudangrass hybrids, that are generally taller, more productive and later, are used for silage and green fodder (50, 85, 112, 294). These plants will thrive in a wider variety of soil conditions than will corn. However, extremely acid or low fertility conditions do not favor large production (85, 112).

A particular characteristic of Sorghum species is that all of them contain at least trace amounts of a cyanogenic glucoside called dhurrin.

This subject will be considered in a later section.

Management and production The total seasonal production of sudangrass and sorghum x sudangrass hybrids depends a great part on the management conditions and also on water availability and N fertilization. In Galicia, few studies have been done with *Sorghum* species. Two reports gave dry matter yields between 2 and 18 t/ha, depending on year, location, number of harvests, and most important, amount of irrigation (208, 243). Some French data presented yields between 14.62 and 15.20 t/ha for sudangrass and between 15.97 and 17.33 t/ha for sorghum x sudangrass hybrids (85). Used for green fodder as a double crop, yields between 2 and 7 t/ha could be expected (143).

In the U.S., a lot of research has been done with sudangrass and sorghum x sudangrass species, mainly in the warmer areas of the country. Most of the results show that cutting management greatly influences total dry matter yield, with an increase in yield with a decrease in harvesting frequency although the quality goes in the opposite direction (50, 132, 323).

Wedin (323), using several *Sorghum* species, obtained mean dry matter yields of 13.46 t/ha with a single harvest at the hard dough stage compared with 4.95 t/ha when the crop was harvested 5 times. However, he did not find significant differences bewteen 5, 3 and 2 harvests, with the overall mean of 8.12 t/ha for these managements. Another interesting point in this study was that varieties differ in their response to management. Some varieties had their greatest yields with 1 harvest but had low yields under frequent cutting, whereas other varieties yielded comparatively more with frequent cutting managements. In Texas, Holt and Alston (132), working with sudangrass, obtained the greatest yields with less frequent harvest and shorter stubble heights. Cutting at 75 cm height, the total yield was 10.8 t/ha, while cutting at early bloom was 16.6 t/ha. Also in Texas, Conrad (50) tested several sudangrass and sorghum x sudangrass hybrids. He found that dry matter accumulates very fast at the earlier stages of growth. He also reported that common sudangrass reached maximum dry matter accumulation by the late flower stage, while some sorghum x sudangrass varieties continued to increase dry matter production through hard dough and others through hard seed. The maximum yield for sudangrass was 8.40 t/ha, while the sorghum x sudangrass yielded from 12.66 to 19.33 t/ha.

Read et al. (259), in Texas, in a variety test with three harvests, obtained dry matter yields between 8.60 and 18.33 t/ha. They found no significant yield differences between the 17 test varieties. In this test, each regrowth yielded less than the previous harvest. On the average, the first cutting yielded 5.72 t/ha, the second 5.04 t/ha, and the third 4.56 t/ha.

Other results have been reported in Tennessee, where they tested several sorghum x sudangrass hybrids at different locations and dates of planting. Higher yields were normally obtained with early planting dates (6.21 to 16.00 t/ha) compared with late plantings (5.83 to 9.98 t/ha) (94).

In Minnesota, a three year average of dry matter yield for sorghum x sudangrass, in a summer crop comparison, was 9.86 t/ha (270).

It is generally recommended that *Sorghum* forage species be fertilized with nitrogen, phosphorus and potassium at rates equal or greater than that for corn (85, 134). The row space recommended in France can range from 20 to 30 cm for sudangrass and hybrids and from 30 to 40 cm for sorghum x sudangrass for silage (85). A study conducted in Illinois did not find differences between 20 and 40 cm row width (32), whereas in California, Worker (338) obtained significant decrease in dry matter production as row spacing was increased from 36 cm to 53, and from 53 to 71 cm.

Crop quality The quality studies done with sudangrass and sorghum x sudangrass hybrids show two main trends. One is that, at the vegetative stage the quality is quite high, but it declines with maturity (85, 134, 263). The second refers to management conditions. It is well-known that increasing harvesting frequency produces higher forage quality (83, 94, 134). These trends are associated with the plant morphology, because as the plant progresses towards reproductive stages or towards maturity, the relative proportion of plant parts changes. Normally the proportion of stems and heads increases. These modifications are known to be an important factor in determining the acceptability of forage to livestock. It is also known that frequent harvests give higher proportion of leaves (83, 94).

Wedin (323), in a harvest frequently study, obtained CP contents of 18.4% with frequent harvests compared with 5.8% with a single cutting, and at the same time the IVDMD values dropped from 70.1 to 56.7%. However, frequent harvest did not increase IVDMD yields per ha.

In Texas, Read et al. (259), in a quality and yield study, found that for all estimates of quality measured, there was a decrease in quality when the regrowth was compared to first cut. The mean CP content for the first harvest was 13.0%, for the second 7.4% and for the third 6.6%. The IVDMD percentages were 63.4 for the first cut and about 58% for the second and third.

Reid et al. (263) in West Virginia obtained 71% digestible energy for sudangrass at the vegetative stage and only 55% at full bloom. Using "in vitro" techniques, they reported values of about 78% at the vegetative stage, 68% at early bloom and 63% at seed stage.

In Minnesota, sorghum x sudangrass hybrid harvest at the late flower-milk stage had 57.7% IVDMD and 9.7% CP. In the same study, corn gave higher values, about 76.9% IVDMD (270). In a more recent study, Conrad (50) compared sudan types with sorghum forage type. He found that IVDMD decreased continuously with time for sudan types (from about 62.9 to 67.1% to 51.6 to 55.7%), whereas with sorghum types digestibility remained fairly stable from flowering through soft dough, although they also decreased after this stage. The values were around 65% at vegetative stage, between 58 and 63.5% at soft dough and between 55.1 and 58.3 at hard seed. These later values are a little higher than the ones reported by Cummins (60). Although both agree in the sense that the digestibility of silage-type sorghum fodder remains quite constant with advancing maturity because of the increasing proportion of high quality heads.

Lippke (174), in an animal feeding experiment, used sorghum x sudangrass hybrids. He found that both animal responses and laboratory analysis showed a decline in forage value with increasing maturity. He reported IVDMD percentages of 73.4 at leaf stage, 68.3 at immature and 58.0 at early bloom stage. At the same stages, the CP contents were 16.5%, 8.7% and 6.9%, respectively, and the ADF percentages increased from 33.8% at the leaf stage, 39.3% at immature to 46.9% at the early bloom stage. In the same interesting experiment, it was shown that the animals fed with forages cut at early bloom stages consistently lost weight, and that the primary factor was the reduced digestible energy intake. The same conclusion was reached by Ademosum et al. (1) and confirmed by Wheeler in his review paper (325) where he states that high animal production is impossible to obtain with this kind of forage alone unless the forage available is of moderate to high digestibility. Ademosum et al. (1) presented ADF values of 29.9 at early stages to 37.8% at 40% plant heading. Related with animal intake is the content of dhurrin. There is some evidence that high hydrocyanic acid potential (HCN-p) in Sorghum makes these plants less acceptable to sheep and cattle than those with lower levels (325). It is well-known that caution should be taken when grazing plants that contain appreciable quantities of the hydrocyanic acid (HCN). Normally, sorghum x sudangrass hybrids contain higher amounts of HCN than sudangrass, although there are a lot of varietal differences. It is recommended not to graze sudangrass lower than 50-60 cm, while sorghum x sudangrass should not be grazed until 70-80 cm of height (85, 187).

Sunflower

Sunflower is a plant member of the botanical family Compositae. It is an erect, hirsute annual herb considered to be adapted to many different environments (182, 267). Sunflower is generally regarded as being drought tolerant because it often produces satisfactory growth when other crops are seriously damaged. It has been suggested that sunflower is a deep-root plant that has the ability to exploit the available moisture in the soil profile to a greater depth than other crops (267), but this claim has not been well-substantiated (182). It appears that sunflower is well-adapted to survive moisture stress, but it is equally apparent that only minor stress may lead to a reduction in the yield potential (182).

The temperature requirements for sunflower are lower than for corn. Satisfactory germination of material of USSR origin has been reported at temperatures as low as 5 C, but the rate of germination is slow and seeds are subject to fungal attack. Temperatures of 8 to 10 C are normally considered as the minimum for satisfactory establishment, while the optimum temperature for crop growth is about 28 C, although temperatures between 18 and 33 C have small effects (182, 267). The crop is generally considered to be tolerant at temperatures as low as -5 C to -6 C in early growth and in the post-flowering phase, but is frost susceptible at all other stages of development. The base temperature used for predicting phenological stages is 7 C (267), although in Australia (182) it is suggested that from buds to first anthesis a better base would be 11 C.

Sunflower is considered not highly sensitive to soil pH, and commercial varieties are grown at pH of about 5.7 to 8. However, genotype differences have been reported (88). The plant is normally grown as an oilseed crop in dryland areas, but recently there has been a renewed interest in the use of sunflower as a forage crop in areas where the season is too short or too cool for corn (68, 78, 117, 240, 276). These reasons were also reported in the early papers in the 1920s (135, 318).

Management and production   Most of the research with sunflower management has been related to its use as a grain crop. According to this, optimum plant populations vary depending on climatological differences (267). In general, plant densities for forage production are higher than for seed production and also higher than for corn silage, and row spacing is narrower.

In Galicia, Garcia (98), with 100,000 plants/ha, reported dry matter yields of about 7 t/ha in early planting dates and about 6 t/ha in later plantings, although in a very dry year these yields dropped to about 3.1 and 1.5 t/ha, respectively. In sunflower, like in corn, early planting dates are recommended for higher yields (78, 220).

In Italy, Duranti et al. (78), using 50 to 60 cm rows and 150,000 plants/ha in a very good year, obtained dry matter yields of about 13 t/ha for early plantings and about 10 t/ha for late dates. However, they reported that the normal yields are between 6 to 8 t/ha. In France (143), planting densities of 140,000 plants/ha and 60 cm rows are recommended. The expected yields should be between 5.5 and 12.0

t/ha. In the same country, Demarquilly and Andrieu (68) obtained dry matter yields between 8 and 10 t/ha with 93,000 plants/ha. With most of these studies, sunflower was harvested between the end of flowering and dough seed stages. Dry matter yields increase when the plant goes to maturity stages.

An excellent study about sunflower for forage has been done by Sheaffer et al. (276) in Maryland. They obtained higher dry matter yields with increasing plant population. A density of 287,000 plants/ha produced more than 143,000 plants/ha and 172,000 more than 86,000 plants/ha. Although in a different year, they did not find significant differences between seeding rates of 172,000 and 344,000 plants/ha. However, in their study higher densities produced thin, weak stalks and sometimes severe lodging. They believed that the yield increases obtained when plant populations went from 287,000 to 344,000 plants/ha were not enough to offset the extra costs. In the same 3-year research, plants were harvested at flowering and most of the forage yields obtained were between 6 and 8 t/ha and the highest was 10.3 t/ha, with a 40 cm row width. Their planting dates should be considered as being late. Yield differences due to cultivar were also observed. However, the two levels of fertilization which were compared, 56-112-112 vs. 112-224-224 (N-P_2O_5-K_2O) kg/ha, did not show significant differences. They concluded that in a double cropping situation following barley, sunflowers can be as productive as corn in terms of dry matter yield. However, in terms of total digestible nutrients (TDN), corn is over twice as valuable as sunflowers.

In the intermountain areas of Central Oregon, Murphy (220) obtained, in irrigated conditions, higher yields for early May plantings because frost eliminated late plantings. The average two-year yields for 11 cultivars was 9.5 t/ha. In this study, significant differences among cultivars were found, and the highest yield obtained was 14.5 t/ha.

In a study carried out in Denmark, corn and sunflower were compared for 3 years, and corn yields were a little higher (10.38 and 9.11 t/ha) than sunflower (8.98 t/ha) (240).

Little information is available for fertilization recommendations for forage sunflower. Robinson (267) reported that grain yields increased with rates of N up to 200 kg/ha, and he wrote that ample supply of K is needed because of the relatively high K content of sunflower compared with corn. Other researchers have found that 50 to 100 kg of N/ha are adequate (188). In France, rates of 70 to 100 kg N/ha, 120 kg P_2O_5/ha and 120 kg K_2O/ha are used (143), and in Italy (78) they considered that the N fertilization has to be between 140 and 200 kg/ha. Some U.S. rates were reported earlier herein when discussing the research done by Sheaffer et al. (276). Murphy (220) in his experiment used 170 kg N/ha and 213 kg P_2O_5/ha one year and 125 kg N/ha and 157 kg N/ha in the second year.

Crop quality Several studies have been published about the forage quality of sunflower and its use for animal feeding. Generally, these studies compare forage quality of sunflower with that of corn. I reported earlier the conclusions reached by Sheaffer et al. (276) in the sense that although the sunflower production can be as high as the corn, its quality is normally lower. In the same study, they found that the quality of the leaves was higher than the heads and the heads higher than the stems. The respective ADF and CP values were: leaves, 19.07 and 24.38%; heads, 23.18 and 11.87%; and stems, 51.79 and 3.94%. The ADF contents for the whole plants showed great variation depending on years and varieties. During one year, ADF varied between 33.03 and 37.34%, while in other years ADF ranged from 47.37 to 56.54% and from 46.82 to 53.10%. However, despite these high ADF values, sunflowers had relatively high IVDMD with Peredovick having an average value of 70.42%. This could be due to early harvesting following flowering as compared to harvesting at dough stage or maturity. Generally, the IVDMD percentages obtained ranged between 63 and 68%. The mean crude protein content for the 3 years was between 8.26 and 12.20.

Demarquilly and Andrieu (68) in France studied the chemical composition and digestibility of sunflower. They found that the IVOMD was about 75% from the period of bud formation to beginning flowering. After this stage, the digestibility decreased about 0.35 to 0.40% daily during the next 5 to 6 weeks. At the grain dough stage, the digestibility values were around 60-65%. They recommend harvesting sunflower for forage at the dough stage. Their conclusions are based on the fact that in this experiment, the voluntary intake by animals was lower at the beginning of flowering stage. Similar studies have been carried out in Britain (117). The results show that the IVOMD declined rapidly with the onset of flowering and at that stage the digestibility was 75% and at the latest harvest 56.9%, while the CP went from 16.3%

to 7.5%. The conclusion was that the high yields and satisfactory animal performance which they obtained suggest that the crop has a potential for ensilage, if the problem of effluents can be overcome. In Italy, Duranti et al. (78) compared corn and sunflower silages. The CP and ADF values for fresh sunflower were 6.28 and 43.28%, respectively, and for corn 4.57 and 28.46%. Furthermore, the "in vivo" dry matter digestibilities of the silages were 57.71% for sunflower and 72.02% for corn. In Denmark, IVOMD values for corn of 77.9% compared with 53.1% for sunflower have been reported (240).

In the last few years, several feeding trials using sunflower have been reported. In some of them, sunflower silage was compared with alfalfa-grass silage (303, 304). The results showed that sunflower silage was an acceptable forage for beef steers and for cows in mid to late lactation. However, corn silage produced a little more milk and the cows had a greater dry matter intake than with sunflower silage (192, 314).

Small grains for forage

In this section, oats and rye for forage production will be reviewed. The great interest that the small grains have as forage producers is reflected in the large amount of research papers published all over the world about this subject (44, 53, 67, 86, 269). In general, oats and barley have been more extensively studied than have wheat and rye.

Cereals cut at the optimum stage of growth produce silage that compares favorably in terms of annual yield and digestibility with much of the hay and grass silage made on farms (53). The stage of harvest is critical in determining the feeding value. Total dry matter production generally increases up to maturity, but the quality follows a different pattern. The distinct digestibility changes of the small grains, compared with herbage grasses, is the main difference between them. For both groups of plants, the relative proportion of the plant parts changes depending on the physiological stage, but in the small grains, the percentage of the grain compared with the rest of the plant increases substantially, which is not true for the herbage grasses. For this reason, the high quality of the grain partially compensates for the decrease in quality of other plant parts (44, 53, 67, 269).

The precise changes of yield and quality depend on the year, location, harvesting stage, etc. but also on the small grain and the cultivar or variety employed. In general, the highest digestibility is, of course, attained at the vegetative stages, then decreases at the heading stage, and finally increases a little bit, or remains stable, at the dough stage (44, 53, 67, 86, 269). Comparing the four main small grains, barley, oats, rye and wheat, rye is normally considered the lower quality cereal and its change in quality may differ from the other grain crops.

In small grains for forage, early fall planting generally gives greater production, although some problems may occur such as diseases, lodging, etc. Larger amounts of N can be used when the crop is to be used for grazing, hay or silage than when it is to be harvested for grain because of less danger of lodging (92).

Oats There are several cultivated species of the genus *Avena* around the world. The most important are *sativa* and *byzantina* (46). However, in Galicia the most cultivated oats belong to the species *strigosa* (179). This kind of *Avena* has been very seldom reported, and only a few articles from Australia and Brazil refer to this species (115, 156, 221, 242, 286, 293). Except in those countries, most of the papers dealing with oats consider *strigosa* as an old kind of oats which used to be cultivated for grain and forage in the more mountainous areas of Northern Europe and in places in Central and Eastern Europe, where conditions are unsuitable for the common oat (17, 46, 327). Sometimes it has been considered as a weed in grain fields.

In Galicia, *A. strigosa* is normally seeded for forage production after potatoes or corn. Compared with local varieties of *A. sativa* and *A. byzantina*, *A. strigosa* thrives better during fall and winter and gives a greater forage production at the beginning of spring than the other species. There are a lot of different local ecotypes, but in general their heading stage occurs about one month earlier than the *A. sativa* cultivars, and for this reason, *A. strigosa* fits very well in intensive forage rotations (176).

In Australia (Queensland) and in Brazil, *A. strigosa* is normally used as a winter fodder for pasture or silage (115, 156, 221, 242). In the U.S.A., *A. strigosa* has been reported to be important in California where it grows in the foothill areas for pasture and forage (46). One variety has been used as a rust tester.

In general, *A. strigosa*, also called sand oat, grows in cool, temperate climate and it is better adapted to poor, shallow soils and to lower summer temperatures than the common oat (327). Since there is practically no bibliography about sand oats, the common oat species, A. sativa, will be briefly reviewed in order to have at least some point of reference.

Oats are best suited to cool, moist climates and next to rye are the least selective of all cereals as to soil characteristics. If temperature and moisture conditions are favorable, any reasonably fertile and well-drained soil is suited to their culture (47). The crop is less sensitive than is wheat or barley to soil acidity. From the moisture aspect, oats require more moisture to produce a given unit of dry matter than any other cereal except rice (47). The minimum temperature for growth in oats is between 3.3 and 4.4 C, and this latter is used as a base for heat unit requirement. The optimum for growth is about 25-31 C and the maximum at 31-32 C (25, 47).

Management and production Some results obtained in Galicia with A. strigosa of different ecotypes gave dry matter yields between 4.20 and 6.6 t/ha at heading stages for fall seeded oats (175). Garcia (98), also in Galicia, used the commercial variety Saia, mixtured with vetch, and reported yields of about 5.8 t/ha and most of the production came from the oats. For late harvests, the yields were about 8.6 t/ha.

In Queensland (Australia), the variety Saia was introduced from Brazil in the early 1950s (115), and it is a highly cultivated variety. Saia is not recommended as a grain oat but as a forage crop. It has been the most popular cultivar and the highest yielding (293). In that area, Saia compared favorably in some experiments with Lolium rigidum and A. sativa for forage winter production. With 3 to 4 cuts a year, the cultivar yielded from 2.03 to 5.07 t/ha, depending on the location, with an average of 17.8% of CP content. In that experiment, the nitrogen content of the plants increased with increasing nitrogen fertilization from 0 to 100 kg N/ha after each harvesting. At zero N fertilization, the N content was about 2.37% and at 100 kg N/ha, it was 3.42% (156).

Also in Queensland, Bowdler and Lowe (23) compared Saia oats with L. rigidum, and they also seeded the plants with several legume species. They obtained yields of 7.53 t/ha for oats-legume mixtures, but of this quantity, 6.88 t/ha were produced by the oats. In a different experiment, Saia was compared with L. perenne, L. multiflorum, L. multiflorum x L. perenne, L. rigidum and A. sativa. Saia gave the highest yields at the first harvest two months after seeding, 1.45 t/ha, but harvested at 4 months, its average yield 2.63 t/ha was inferior to Italian ryegrass (4.08 t/ha) (221).

A. sativa harvest at heading stage can produce about 5-10 t/ha in France, and cut at later stages the production can increase about 3 t/ha (143). In New Zealand, several trials have shown that autumn-sown oats can produce in the spring about 15 t/ha at the milky-ripe stage of growth (191). In England (53), the yield of winter oats at maturity stage for forage can produce about 11.4 t/ha. In the U.S., management studies showed higher yields with less cuttings (34, 131). They also obtained greater yields with higher N fertilization. At zero nitrogen, the mean dry matter production was about 1.20 t/ha while with 450 kg of N, the yield increased to 3.50 t/ha (34). Similar results have been reported by Morey et al. (211) in Georgia. With a mean of 3 to 4 cuttings, the dry matter yield with zero nitrogen was 1.68 t/ha, while with 180 kg N/ha, it was 3.60 t/ha and with 450 kg N/ha, it was 4.25 t/ha. In Kansas (231), oats harvested at dough stage yielded between 5.54 and 8.23 t/ha, depending on the variety and location. A study in Georgia (52), with 4 to 6 cuttings a year, presented 3-year averages of 9.3 t/ha for the best variety at the best location and 2.30 t/ha for the worst cultivar at the worst locality. The general mean production was between 6.30 and 7.6 t/ha. In these tests, the last cutting date was about mid-May, and the planting time was mid-October.

The fertilization patterns varied depending on the soil tests, production expected and country. In France, the I.T.C.F. (143) recommended 100 to 150 kg N/ha, and 120 kg/ha of P_2O_5 and K_2O. In England (180), the same fertilization is used as for wheat, but with less nitrogen. The amounts are 50 to 60 kg N/ha, and 40 to 50 kg/ha of P_2O_5 and K_2O. In Queensland (Australia), 50 to 75 kg N/ha should be applied at planting for oats in rainfed conditions. A further 50 kg N could be applied following a grazing (293). In the Georgia variety test (52), the fertilization was 80 kg N/ha (split application), and about 50 kg/ha of P_2O_5 and K_2O.

Crop quality When oats, generally *A. sativa*, have been compared for quality with wheat and barley, it has normally produced the lowest quality crop (45, 67, 86, 184, 231). In Galicia (175), CP contents between 16.72 and 19.79% have been obtained with A. strigosa, harvested about 3 weeks before heading. At the same time, the ADF percentages were between 29.41 and 37.32%. In New Zealand, McDonald and Wilson (191) reported digestibilities of about 90% at vegetative stages, while it declined rapidly to between 55 and 65% at stages near maturity. In North Dakota (82), two spring high-protein varieties gave 15.6% CP at 50% heading while at maturity the CP content was only 10.8%. In Canada (86), several spring crops were compared and the digestibility reported by oats at the maturity stage was about 52%, which was lower than the digestibility of wheat, barley, triticale and even rye. At the same stage, the ADF was between 34 and 38%.

In France, Demarquilly (67) compared oats, wheat and barley. He found that the digestibility decreases rapidly to time of grain formation, and that the ingestion for oats was maximum at the dough stage. At this stage, IVOMD was 57.0% for oats, 62.7% for barley and between 61.8 and 63.4% for wheat. However, at the end of flowering, all crops had similar digestibilities of 65%. The CP content for oats was 10.1% at flowering and 6.3% at the dough stage, while the respective productions were 5.4 and 10.6 t/ha.

Other research in Canada (45) reported that wheat and barley cultivars tended to contain higher energy digestible levels than oat cultivars at mid-dough stage. The IVOMD values for oats silage was 53.5%, while for barley it was 57.8% and wheat gave a mean of 55.8%. The CP and ADF were about 11.4% and 32.26%, respectively, for oats and 12.5% and 34.11% for wheat.

In England, Corrall et al. (53) found that at maximum yield of dry matter the organic matter digestibility for winter oats was 51%, and for spring oats 50%. At the same point, rye was only 46% digestible, spring barley 63% and wheat about 56%. In Oklahoma (133), IVDMD values for oats were 64.8%, which were a little lower than for barley and much lower than for wheat and rye. In Kansas, Oltjen and Bolsen (231) reported that oats had the lowest digestibility and yielded the least digestible dry matter compared with barley and wheat when harvested at early to mid dough stage of maturity. Crude protein for oats was between 8.0 and 8.6%, and the IVDMD values about 50.5%. At the same stage, digestibility values for wheat were around 56% and for barley 60%.

In Minnesota, working with spring grains, Marten (184) reported 77.6% IVDMD for oats at boot stage, and 56.8% at dough stage. The CP concentrations at these stages were respectively 20.5 and 11.5%. The digestibility of oats was consistently lower than that of wheat, barley or triticale.

Other reports using small grains for pasture and harvesting them 3 to 4 times obtained somewhat different results. Using the nylon bag "in vitro" technique, Morey et al. (211) reported mean digestibilities between 73.3 to 75.6% for oats, 70.8 to 74.0% for wheat, 69.5 to 77.1% for rye, and 71.9 to 76.9% for barley.

As it has been shown, the quality of the forage depends a lot on the stage of harvesting and also on the grain/stover ratio. For these reasons, the quality of _A. strigosa_ can vary much. However, since this plant is normally used for green forage and since its stem quality is better than the A. sativa; at least in Galicia (104), the digestibility values at the vegetative stage can possibly be higher than those of A. sativa.

Rye   Amongst the small grain cereals, winter rye is known as the most winter hardy. Winter rye has been known to withstand temperatures as low as -35 C without the protection of a snow cover (227). Germination of the crop will take place at temperatures as low as 0.6 C, the optimum germination temperatures being in the range of 13 to 18 C (227). The crop will tiller slowly at 1.1 C to 4.5 C, more intensive tillering taking place at temperatures up to 16 C. The optimum temperature range for vernalization of winter rye is 1.1 C to 3.9 C over a time period of 20 to 55 days. The length of time varies with cultivar and there appears to be a close relationship between the time requirement and the area of origin of the cultivar.

Rye is a relatively drought-resistant crop and in addition, the early maturity of the crop, when grown for grain, enables it to evade extremes of summer heat stress (181). On a world basis, the crop is grown under a wide range of rainfall conditions with the lower limit being about 381 mm per year. The vigorous root system of rye and its ability to utilize autumn and winter precipitation are important factors in its ability to withstand spring drought (181). The root system is more freely branching and goes deeper than that of wheat, barley or oats (227). The highest yields of rye usually are obtained on rich, well-drained loam soils; however, rye is more productive than other grains on infertile, sandy or acid soils (181, 187).

In Galicia, rye is the most used cereal crop. Its characteristics and mainly its ability to grow on poor, acid soils unquestionably are the reasons it is widely used. However, with improving fertilization practices, wheat is replacing rye in certain areas. The plant is used for grain as well as for forage production and is included in most of the traditional crop rotations of the region (176). The varieties used in Galicia are local ecotypes, well-adapted to their growing locations. They are tall plants, generally receiving little or no fertilization. The local ecotypes differ in the length of their growing season, but compared with Central European varieties like Petkus, most Galician cultivars are short season cultivars (104).

In general, rye is grown around the world for winter forage production as a double crop in areas where no other plant can do better. It is also grown where winter forage is necessary for pasture or green fodder systems. Rye is more reliable for forage production with late fall seedings than any other crop (74, 104, 209).

Management and production As in all the cultivated species, yield depends on a lot of factors, and one of them is management. In general, there is a decrease in yield with increasing harvesting frequency (34, 131). In Galicia, rye for forage is normally seeded after corn or potatoes and it is very well-adapted to this system because, at least in the coastal ares, it heads about mid-March and it is used at this stage, which leaves adequate time to prepare the land for the next crop. Several results have been reported at Mabegondo (INIA's research center). Two different regional ecotypes harvested at the beginning of

February yielded about 1.75 t/ha, while cut at the heading stage, they gave between 4 to 6 t/ha (104). The normal yield was about 4 t/ha, while 6 t/ha was from an excellent crop. On the other hand, the variety Petkus cut on the same day in February yielded 0.22 t/ha, although its final production at the beginning of April was very similar to the local ecotypes and produced about 4 t/ha. With the local varieties, if the harvest was delayed until dough stage, yield increased dramatically up to about 13 t/ha; however, the quality was low because with these ecotypes, the grain/straw ratio is low. At the mature stage, the plants can be as tall as about 2 meters.

In France, the I.T.C.F. (143) considers between 5 to 10 t/ha possible yields of rye harvested at the heading stage, and between 8 and 15 t/ha if the crop were harvested at the dough stage. In Ireland, Keane (155) compared several varieties, sowing dates, seeding rates, and N fertilization rates for winter and spring production. The two year mean total production of two harvests was about 6.35 t/ha for all the varieties. Different seeding rates, time of fall sowing and N fertilization management did not give significant differences. In Germany (18), yields between 6.88 and 10.99 t/ha have been reported for September seeding harvested in May. Neither this study nor the previous one in Ireland gives the stage of growth at cutting. Increasing production reduced the protein content.

In Denmark, Mølle (200) studied the production and quality of forage rye at different cutting dates. At ear emergence, the dry matter production was 3.69 t/ha, and 15 days later it was 5.52 t/ha. At the same time the CP content and the digestibility values decreased. In Scotland, Wilson and Wilkins (337) reported dry matter yields of 1.79 t/ha by mid-April, while a month later the production rose to 5.82 t/ha. Also in Britain, Corrall et al. (53), in an excellent work, compared several small grains (barley, oats, rye and wheat) and corn. They found that rye was the crop that gave the greatest dry matter yields (13 t/ha), although its IVOMD values at this high yield stage were very low at 46.51%. When comparing the yield of digestible organic matter per ha, corn ranked first, barley second and rye third, but very similar to oats and wheat. In Canada, Fisher and Fowler (86), in a prediction forage value study for small grains, compared wheat, rye, barley and triticale. In this research, rye was the highest yielding crop, with about 12.5 t/ha at the mature stage.

Several studies have been published in the U.S. related with rye for forage. In Georgia, Morey (209) reported dry matter yields of 8.10 t/ha with 4 clippings for the highest yielding cultivar. In a different test, a 3-year mean for the best cultivar was 6.80 t/ha. Also in Georgia, a small grain fertilization study (211) gave higher yields for rye at all levels of nitrogen than oats, wheat or barley. At zero nitrogen, the dry matter yield was 3.13 t/ha, while at 450 kg N/ha, the production raised to 6.25 t/ha. The problem with rye was that by late March, the stem grew rapidly and the crop becomes stemmy and of poorer forage quality. In Oklahoma, Horn et al. (133) studied the forage quality and production of several small grains (wheat, barley, oats and rye). Rye gave the highest production, about 2.22 t/ha by mid-March.

In a similar study in Michigan, Helsel and Thomas (122) found that both early and late rye yielded more dry matter than the other crops, late rye produced 8.1 t/ha and early 6.9 t/ha. However, the quality decreased as harvest was delayed. For this reason, they concluded that rye should be harvested at early heading to obtain quality forage even though yields are lower than at later stages of growth. This is also the general conclusion in most of the reported papers.

The fertilization of rye has not been extensively studied, mainly because it is normally grown on unfertilized areas. In Australia (181), the same fertilization as used for wheat is recommended, and in France (143) for forage rye 150 kg N/ha and 120 kg/ha of P_2O_5 and K_2O are advised. Similar amounts of nitrogen and phosphorus are needed in Georgia (211) for moderate grazing and grain production, although only about 80 kg/ha of K_2O are recommended. In Denmark (200), researchers found no differences in dry matter yield between 100 kg N/ha and 150 kg N/ha, although the CP content of the forage crop increased a little more than 2%.

<u>Crop quality</u> In general, rye is considered to have the lowest forage quality of the small grains. For this reason, in order to obtain good quality forage, rye is normally harvested at earlier stages of growth than the other small grains. In Galicia, in the previously reported study (175), the CP and ADF percentages on February harvests were 24 to 26% and 24 to 26%, respectively. However, by mid-March at the early heading stage, the CP was 14 to 16.9% and the ADF between 36.69 and 39.87%.

In Ireland, Keane (155) reported mean CP contents of 22.3% and IVDMD values of 84.3% at the beginning of April. By the end of May, the CP dropped to 12.5% and the digestibility to 63.8%. In the study conducted in Germany (18) which received 130 kg N/ha, the CP at the end of April was 15.19%, whereas by late May it was only 10.2%. Mølle in Denmark (200) found that at ear emergence, the CP content was about 15.1% and IVOMD was 75%. Fifteen days later, the CP was only 11.35% and the digestibility 67%. During other years but at a similar physiological stage, the CP percentages were between 18.4 and 26.2% at heading, while the digestibility was 86%. In Scotland, Wilson and Wilkins (337) reported IVOMD of 72.0% at vegetative stages, 61.6% at ear emergence, and 58.6% at heading. However, the yield of digestible organic matter per ha increased as cutting was delayed. Corrall et al. (53), in their stage of growth and quality study, obtained IVOMD of more than 70% at vegetative stage and with a N content of about 3%. However, at maturity the digestibility dropped to 46 to 51% and the N percentage to less than 1%.

In Canada, Fisher and Fowler (86) presented IVOMD of about 70% at the late boot stage; the the values decreased to 54 to 56% after heading and finally increased a little to about 62% at the dough stage. At the same time, the ADF contents were around 30% at late boot stage, 40% 20 days later and dropped to about 30% at maturity. In Oklahoma (133), IVDMD values of 73.2% have been reported for mid-March harvests. In Georgia (211), using the nylon-bag technique, the digestibility values reported for rye which was clipped about 4 times were between 66.8 and

74.1% one year, and 74.5 and 78.9% the following year. Meanwhile, the CP contents averaged 20.45% with zero nitrogen and 26.38% with 450 kg N/ha. At Ames, Helsel (121) obtained CP and IVDMD values of 9.40 to 12.5% and 62.6 to 70.2%, respectively, for fresh rye.

Hairy vetch

This legume is one of the most winter hardy vetches. Its cold resistance is shown by the fact that it is seldom winter killed in the northern part of the U.S. or in southern Canada (169). In regions with a mild winter, it makes its growth during the fall, winter and early spring. It is adapted to sandy and poor soils as well as heavier textured soils (169), and it tolerates acid soil conditions better than most legume crops (125, 159). It is normally used with small grains for hay, silage, pasture or winter cover crop (125, 169, 232, 316).

Production and quality There are very few papers related to *Vicia villosa*, and in most of them the plant is seeded with a companion crop. In Galicia, hairy vetch mixed with sand oats as a winter crop after corn, Garcia (98) reported dry matter yields of about 5.8 t/ha. However, the study does not tell the proportion of the yield that corresponded to hairy vetch.

In Central Spain, Treviño and Caballero (308) compared yield and quality of *Vicia sativa* and *V. villosa* at different growth stages. They obtained higher yields for *V. sativa*. For *V. villosa* yields of 2.66 t/ha at vegetative stage and 5.99 t/ha at end of flowering were reported. At these two stages, the CP and ADF percentages were 31.40

and 20.85%, respectively, at the vegetative stage and 21.55 and 29.92% at end of flowering.

From a study conducted in Canada (321), it was concluded that vetch was not a particularly useful crop at Ottawa. This conclusion came because vetch alone gave inadequate yields between 1.9 to 2.1 t/ha. However, with oats, the yields were more acceptable, 3.05 to 5.50 t/ha, and the forage would be expected to have better quality. In the U.S.A., hairy vetch is cultivated mainly in the South and Pacific Northwest as a winter crop (125). The published results differ. In a study conducted in Maryland (319), mixtures of small grains with hairy vetch yielded less than small grains alone. Ahlgren et al. (2), in New Jersey, compared several winter grains alone and with vetch. They concluded that the average dry matter yields of the small grains alone were similar to those obtained from the comparable small grain and vetch mixture. However, the inclusion of winter vetch notably increased the yield of protein per ha. Robinson (268), in Minnesota, compared oats with oats plus vetch. The dry matter yields of both oats alone and vetch-oats mixture were similar and about 4.97 t/ha. However, the protein content was much higher for the mixture, 10.2% compared with 8.4% for oats alone.

It appears clear, from all these previous studies, that although the inclusion of vetch increases quality, most of the dry matter production comes from the cereal and consequently, the harvesting stage of that plant is the most important fact in determining the yield and quality of the mixture. For the mixtures, the amount of N fertilizer used is normally less than for the cereal alone.

Forage rape

Brassica napus L. ssp *oleifera* is a crop normally grown for seed, although in recent years, certain varieties have been used for forage. Most of the published literature about this forage crop comes from Europe, mainly the United Kingdom and France where the plant is most extensively cultivated. In the cooler region, forage rape is seeded as a spring crop although its general use is as catch crop after the spring or winter crop or as a winter crop in double cropping systems. It is normally utilized for autumn-winter grazing when there is no other forage available (116, 143, 159, 180).

Forage rape will grow in a wide range of soil and climatic conditions, provided the soil is well-drained (the plant is particularly susceptible to waterlogging) and the pH is over 6.0. Like almost all the *Brassica* species, forage rape is reputed for giving a highly digestible crop, but on the other hand, it is susceptible to several leaf diseases. Another common problem with *Brassica* plants is that anemia of the animal may occur due to the plant content of S-methyl cysteine sulphoxide and in addition thyroid enlargement can result from glucosinolates which are also present in these crops (342).

Production and quality When seeded as a catch crop during the fall, dry matter yield usually increases with early plantings, provided that water is not limiting. Sheldrick et al. (277), in Britain, obtained dry matter yields between 2 and 3.5 t/ha by mid-December for August seedings. The IVDMD percentages were about 70%, and the CP content around 24%.

Harper and Compton (116) in Scotland did not find a benefit from sowing rapes earlier than mid-June; however, dry matter yields decreased from September to November sowings. The dry matter yields obtained ranged between 3.5 to 4.5 t/ha during a stress year and between 6 and 9 t/ha with early seedings in an unusual year. The dry matter concentrations were 13 to 16%.

Other British results for forage rape reported yields, after spring barley, at 3.0 t/ha in December with 18 to 20% CP and 72% digestibility (99). Compared with other species of Brassica, forage rape resulted in lowest level of wastage for grazing sheep (16). Australian authors (293), using forage rape for dairy cattle, reported that animals found the crop unpalatable until they became accustomed to it and that rape can only be given to dry stock because it gives off flavors to the milk. They presented 3 to 4 t/ha as a normal yield, but in a favorable year rape can produce up to 7 t/ha. In New Zealand, comparing several plants, an 81% digestibility was presented for rape (15).

Forage rape is used for silage in several areas of France. It is recommended that the crop be harvested at the beginning of flowering stage. At this stage, the production could be between 3 and 9.0 t/ha, depending on fertilization and other management practices, with an IVOMD of 75-80% (145, 216). Also in France, Dumont et al. (77) calculated the "in vivo" feeding value of the plant. In this study, the dry matter content of fresh rape was about 13%, the CP content between 15.3 and 19.4%, and the digestibility coefficient around 82%. The dry matter production was between 2.3 and 4.0 t/ha depending on the year and the physiological stage. When the rape was ensiled, they found that the low dry matter content of the crop caused high silage losses of between 13.6 and 34.8%. The digestibility of the organic matter was a little higher than 80%.

In the U.S.A., a few recent articles have been published about rape for forage. It appears that it is grown mainly in the southern areas. Although some reports show that in Iowa rape is still used as a forage, but mainly it is used as a pasture for swine (159). In Pennsylvania, with August plantings, yields of 3.81 t/ha have been reported (152). The CP content, in this report, was about 25% for the leaves and 10% for the stems, and the quality was very satisfactory with a IVDMD of about 85%. A study in Florida with several related Brassica species reported rape yielded 4.6 t/ha at early plantings and only 2.04 at late plantings. The CP of the crop ranged from 17.4 to 24.1% and the digestibility was high between 86.4 and 90.0% (154). However, in this study the plant they called rape was not Brassica napus as reported but a hybrid of B. napus ssp. oleifera x tetraploid B. chinensis which normally is more leafy than rape and may yield less than rape (178). In both of the U.S.A. studies presented, the authors reported insect and leaf disease problems.

The fertilizer recommendations varied depending on the sources. In Australia (36), the recommendations are similar to that for wheat in a given area. In France (143), 100 kg N/ha, 80 and 100 kg of P_2O_5 and K_2O per ha are generally advised. In England, as a catch crop forage, the amounts suggested varied between 75 to 190 kg N/ha, 40 to 50 kg of P_2O_5 and 40 to 100 kg of K_2O per ha, although the highest amount of N is used only for spring rape (180).

Pasture Species and Mixtures

A temporary grassland can have a great variety of species and grass-legume associations. However, not all forage species have the same climatic requirements. An easy way to divide the herbage species is using their temperature basis. According to this criterion, they can be divided into temperate and tropical species (167). For many temperate and Festucoid grasses and legumes, the optimum temperature for dry matter accumulation and extension growth is between 20 to 25 C. Some growth is possible at temperatures down to 5 C and at the upper extreme, most species cease growth in the range from 30-35 C. On the other hand, tropical grasses and legumes have an optimum and an upper and lower temperature limit for growth 10 C higher than the temperate grasses (194).

Common species in different areas of the world

Galicia   For the type of climate predominant in this region, the species normally sown are temperate species (341). The most common species are: *Dactylis glomerata* L., *Festuca arundinacea* Schreb, *Lolium multiflorum* Lam, *Lolium perenne* L., *Phleum pratense* L., *Trifolium pratense* L. and *Trifolium repens* L. Alfalfa (*Medicago sativa* L.) and other species are also grown but at a lesser amount. Alfalfa, in particular, is not very popular in the area and farmers have a lot of trouble to grow it, mainly because of the region's acid soils.

However, the really extensively cultivated species, among all of the mentioned above, are Italian and perennial ryegrasses, cocksfoot, and white and red clover. Several associations have been recommended throughout the years (248). At the beginning of the century, formulation included up to 8 or 9 different species. Posterior studies during the mid-60s reduced the number, ending with several simplified mixtures. The most popular are still used and are called F-2 and F-4. F-2 is a short duration prairie and includes Italian ryegrass, cocksfoot, red and white clover. F-4 is a long duration sward and contains perennial ryegrass, cocksfoot, white and ladine clovers.

Research on grass-legume association is an important area of study conducted by the I.N.I.A. (Spanish Institute of Agricultural Research). Actual work is oriented to investigate reduced grass-legume mixtures (248). A brief review of the species and mixtures commonly used in other countries will help to situate Galicia in a correct world agricultural zone.

Europe and New Zealand The importance of grassland in Britain is well-known. In this country, a popular mixture of the 20th century has been the Cockle Park mixture that contained 6 species, perennial ryegrass, cocksfoot, timothy, red and white clovers and trefoil. The modern seed mixtures have fewer species, normally perennial ryegrass and white clover, but often contain many varieties (166). Increased fertilizer usage, the availability of varieties bred for specific characteristics and a better appreciation of competition between plants have justified the recent trends towards the use of simple seed mixtures. It is now a common practice to establish a sward from a single grass species with or without a legume (128). The ryegrasses account for over 80% of seed sown, with timothy, cocksfoot and meadow fescue accounting for 8.5 and 3 percent, respectively (128). The most extensively used legumes in Britain are red and white clover (180). In New Zealand, the ryegrass-white clover association dominates the pasture of this country (24). In France, the main pasture species change within the country, but in general, the most extended are Italian and perennial ryegrasses, cocksfoot, tall fescue, timothy, white and red clover and alfalfa (145, 330).

United States It is not easy even in a huge country like the U.S. to find an area with similar pasture species to that of Galicia, New Zealand, or England. It is not only the climate requirements that need to be similar, but also the type of agriculture. In trying to find in which areas of the U.S. there is grown the five main Galician herbage crops (perennial and Italian ryegrass, orchardgrass, and red and white clover), one comes to the conclusion that there is no one area where all five species are extensively cultivated. The area with more similarities is, according to Semple (273), the natural area 5-a, which includes the coastal area of Oregon, Washington and part of California with a humid winter.

Starting with the Italian ryegrass, it looks like it is grown in region 5-a and also in the southeastern part of the U.S. The perennial ryegrass is almost unknown as a forage crop and is used as a turf plant.

In Europe and other parts of the world, these plants are normally THE HERBAGE CROPS, while in the U.S. they are not very important. As an example, little of the literature used in the chapter "The Ryegrasses" in the book Forages (89) was from the U.S. This chapter includes both ryegrasses and it is difficult to find any meaningful U.S. results. Another exmaple is the important agricultural publication Agronomy Journal. In the last 10 years, there are no more than 15 articles related with ryegrasses and most of them are not forage or seed oriented. Comparing these examples with other plants like orchardgrass, alfalfa, Kentucky bluegrass, timothy, etc., it is very easy to see the difference.

The other three species are generally grown in wide areas of the U.S. Orchardgrass is grown in the central and northeastern part (150). Red and white clover are grown in most of the U.S. except in the central-western states, which are included in the natural areas 3 and 4 according to Semple (273). In the chapter dedicated to white clover, Leffel and Gibson (170) make the comment that 70% of the area dedicated to this crop is in the southeastern U.S.

Of the grass-legume mixtures seeded in the country, practically all of them are different from those used in Galicia. Most of the U.S. associations are based on alfalfa as a legume and on orchardgrass, tall fescue, timothy, bromegrass and Kentucky bluegrass among the grasses. In France, the mixture alfalfa-orchardgrass is also used (330) but not in Galicia. The other grasses also are not used much. Among the mixtures described in the book Forages (119), there is only one which is similar. It is the association of orchardgrass or perennial ryegrass and white clover described as the typical pasture mixture for the subhumid part of the continental climatic zone in the Pacific Coast states (111).

Pasture species, general comments

A lot of different species are used for pasture around the world, and several reviews have been written (119, 287) about these plants. However, in this literature review, only the main species used in Galicia on the species employed in the experimental part of this dissertation are going to be examined. These are Italian ryegrass, perennial ryegrass and orchardgrass among the grasses, and red clover, white clover and alfalfa for the legumes.

Italian ryegrass

Italian ryegrass is a tufted annual or short-lived perennial (287). In general, it is possible to say that there are two kinds of Italian ryegrass, the normal that can be fully productive for 18-24 months, and the annual or Westerwald ryegrass that may be regarded as a short-lived ryegrass. Following spring sowing, it will flower in the same year and act as an annual. It is useful where high production is required within 3 to 6 months from sowing (130). Italian ryegrass has an easy and quick establishment even in not well-prepared land, and it is very competitive with other species and weeds. Its production is rapid and by the end of winter or even by the end of fall when seeded early in the season (mid-September) (340). This short-lived grass is used generally for grazing and silage, it can be mixed with red clover to make a better silage, and it is rather independent of the soil pH, if appropriate fertilization is provided (195). However, this species is medium to very cold sensitive and this limits its growth and use in cold winter climates (119, 145). The threshold for shoot growth is about 1 C, but its optimum growth temperature is around 20-25 C (280). On the other hand, it is severely affected by summer drought which limits its production life (340). The seeding time depends on the severity of the winter and cold tolerance of the species. It is normally fall seeded in areas with mild winter month temperatures. In certain areas of Europe, Italian ryegrass is seeded in the fall and double-cropped after corn in intensive forage production systems.

In Galicia, Italian ryegrass is a part of a very common crop rotation, followed in the north and south coastal areas, where it is intercropped with corn or double cropped after corn. The varieties used in these systems are local ecotypes well-adapted to the crop sequence. They head by the end of March while the commercial varieties of central Europe origin headed much later, usually during May. However, the total production of the local ecotypes is not higher than the commercial varieties, although they begin growth much earlier in spring (250).

In certain areas of France, they make the distinction between Italian ryegrass 12 months and Italian ryegrass 6 months. The first is seeded in the spring and the second in the fall after corn. The first type lasts for about 12 months before the next corn crop, forming a short-lived temporary pasture. The Italian ryegrass 6 months stubbles are plowed under before the next year of corn, and it is used mainly for silage. For the Italian ryegrass 6 months, the Westerold varieties are normally used while the normal Italian ryegrass is used for the 12 month crop (144). Italian ryegrass is also a very popular crop in England, Holland and also in other countries where the weather allows its growth.

The importance of the Italian ryegrass in the U.S. compared with some countries in Europe is very little. As a matter of fact, in the last 10 years there have been fewer than 5 papers related to Italian ryegrass published in the Agronomy Journal, and most of them concern Italian ryegrass as a weed in wheat crops. In the U.S., Italian ryegrass is generally grown in the southeastern states, and it is used mainly as a winter pasture crop.

Production, management and fertilization   Italian ryegrass is considered a very productive plant; however, the yield depends on several factors such as weather, management and fertilization. Italian ryegrass is a very nitrogen-demanding plant and consequently responds very well to the application of this element. Some of the results reported in several countries will be presented.

Galicia   In this region, most of the Italian ryegrass production occurs during the spring. Recent data from 1980 show that the average yield of the best fall seeded varieties was 11 t/ha of dry matter at Mabegondo (INIA-Research Center), 15 t/ha and 8.5 t/ha at Grado and Puebla de Brollon, respectively (both are INIA's-Research Stations). For these three locations, spring production was about 90%

of the total yearly production. The yearly amount of N fertilization was 180 kg/ha (107).

The production of Italian ryegrass also depends on the cutting frequency, with generally higher yields with less harvests. However, the forage quality decreases with fewer harvests. Some results obtained in Galicia in 1966 gave yields of about 20 t/ha with 2-3 harvests compared with 11 t/ha with frequent cutting (6 to 7 times a year) (341).

Other countries   In northwest France, high production of Italian ryegrass is based on heavy nitrogen applications (300-400 kg N/year) (253). However, there is a concern about using such large amounts of N. Various studies carried out in this area of France reported yields of about 2.7 to 4.9 t/ha for Italian ryegrass seeded after corn and harvested by mid-April. The production increased to 5.5 to 7.9 t/ha if the crop was harvested during mid-May at the heading stage (256). Another French paper showed yields about 9 t/ha by November for the variety Tetrone when seeded at the beginning of April (144), while a study conducted in 1962-64 gave about 13 t/ha with 200 kg N/ha/year.

In Britain, Camlin et al. (38), using the cultivar RvP, obtained mean yields of 18.8 t/ha with 300 kg of N/year and only 6.7 t/ha with 30 kg N/ha. In the same country, Hunt (138) reported annual yields of 15 t/ha and 12 t/ha for the first and second year, respectively, both with heavy N applications. Wilman (331) studied the regrowth of Italian ryegrass following a cut in late April with varying amounts of N fertilization. He found that the highest yields of dry matter (9528 kg/ha) were recorded after 11 weeks with 196 kg N/ha. Research done in Atlantic Canada (161), with Westerwold ryegrass cv. 'Promenade' seeded during mid-May, reported yields from 6.26 to 9.03 t/ha, with 120 kg N/ha, and with a delay of the first harvest. The quality was consequently a little lower.

In the U.S., variety tests with Italian ryegrass have been done in several states. In Georgia, the average production of the best cultivars was about 7 t/ha with 210 kg N/ha and 4 to 6 clippings a year (210). At Mississippi in 1977, the yield of the best cultivars changed depending on the location but with three cuttings with the last about the beginning of May, and using 225 kg N/ha, the best results gave 8.4 t/ha (80). At Louisiana, yields of about 9.44 t/ha have been reported (124).

Crop quality The studies show in general the characteristic increase in yield and decline in digestibility associated with the change from the vegetative to reproductive state as harvest is delayed.

In a recent study in England (127) which compared the forage quality of two cultivars with different origins, RvP from Belgium and Bb 1277 from Po valley of Italy, the nutritive value of the leaves (dry matter digestibility) was the same for both cultivars, and the value was higher and declined at slower rate with increasing maturity than that of the stem. The stem of Bb 1277 declined in dry matter digestibility (DMD) at a significantly slower rate than RvP. The leaf DMD went from 83.2% to 76.9% and the stem DMD from 79.5% to 62.1%. In this study, samples were collected at 4-day intervals during a 28-day period. The author concluded saying that "As Italian ryegrass is utilized extensively for conservation and harvested during the reproductive growth phase, when the stem fraction can contribute a very large proportion of the total dry matter yield, the nutritive value of the stem fraction is of main importance." In the study reported by Wilman et al. (333), the organic matter digestibility after the April cut went from 67.1 to 46.3% 14 weeks later, with an average of 58.6%. French data (144) showed a 75 to 80% in vitro organic matter digestibility (IVOMD) at the leaf stage, 65 to 70% for the heading stage, and values of 62 to 65% were reported for the heading stage of the aftermath. Data from trials carried out in England by the NIAB (287) indicate that S22, one of the latest heading cultivars, is at 70% dry matter digestibility at 50% ear emergence. The same publication showed an average of 19% crude protein (CP) for the cultivar S24 and 17.5% for S22 on simulated grazing (9 cuts). On the other hand, the CP content was reduced to 8.5% for S24 and 6.5% for S22 10 days after ear emergence. The classic paper from Aldrich and Dent (3) showed about 80% dry matter digestibility in early season and decreases to about 60 to 65% after ear emergence, although total dry matter production was increasing. However, the total yield of digestible dry matter, leveled of a little after ear emergence.

Data obtained in Georgia (210) presented in vitro dry matter digestibility (IVDMD) of 82.5% for the cultivar 'Gulf', the most digestible by March 31, but the average of all varieties was about 62%. The mean CP content was 12.77%. However, for earlier harvests on March 4 the mean CP was 22.36%. At Louisiana, however, the cultivar Gulf was reported to be the least digestible with 64.6% of IVDMD, while the variety HI 51-3 was the most digestible with 69.4%. On the other hand, the digestibility decreased from 78.5% in February to 56.8% at the fifth cutting during May (124).

In Arkansas (290), mature Italian ryegrass hay was reported to have 9% CP and 53.9% acid detergent fiber (ADF). In Texas, Nelson and Rouquette (226) evaluated protein and neutral detergent fiber (NDF) levels of 18 varieites, and they found a seasonal increase in NDF content and a decrease in protein. NDF values in December ranged from 29 to 32%, while in May NDF increased to 47 to 54%. Protein levels decreased during the growing season from about 25% in December to about 13% in late May.

The study reported by Kunelius (161) in Canada presented mean IVDDM values ranging from 73.3 to 76.3%, with N contents of 2.27 and 2.89%, respectively.

Perennial ryegrass

This plant is easy to establish, although not as easy as Italian ryegrass, and is well-adapted for long-term pastures. Under comparable management conditions, the digestibility of perennial ryegrass is not exceeded by any other grass species. It is not surprising, therefore, that the species has received the greatest attention by plant breeders in Western Europe (128). In general, it is the most productive of the perennial grasses and is capable of responding to high fertility.

Perennial ryegrass withstands the cold weather better than the

Italian ryegrass; however, it does not grow well in hot dry climates. In constant environment conditions, the optimum temperature for growth is generally between 20 and 25 C, depending on plant age, nutrient status and other environmental conditions (287). In hot climates, the occurrence of dry spells specially in summer appears to be a critical factor in the persistence of perennial ryegrass (167). For desirable growth, it requires an annual rainfall of between 850-1300 mm and mild climate during the growing season. However, it has the ability to survive long cold winters. For these reasons, perennial ryegrass is a very popular crop in the west-central European countries (some parts of France, Britain, Belgium, Ireland, Holland, etc.) and in some parts of New Zealand. In Britain and New Zealand, it is the most common specie seeded for grassland (166). Perennial ryegrass is found on soils with pH values of 5.0 to 8.0, but its optimum pH range is 6.0 to 7.0 (287). Perennial ryegrass is also used as a common component for pasture mixtures, with the most common being a white clover-perennial ryegrass mixture.

In the U.S., perennial ryegrass is used very little compared with Europe. In the last 10 volumes of the Agronomy Journal, there are fewer than 10 papers in which perennial ryegrass is included, and in most of them it is viewed as a turfgrass plant.

Production, management and fertilization Perennial ryegrass is considered a very productive plant, and its management and fertilization has been the subject of many studies. In a recent symposium of the European Grassland Federation (76, 129, 213, 254, 313) entitled

"The Role of Nitrogen in Intensive Grassland Production," most of the papers are related to N fertilization of perennial ryegrass swards. The method followed in England and Holland for the intensification of herbage production is based on large amounts of N on perennial ryegrass. In Holland, an average of 250 kg N/ha is used and in many commercial farms the quantity is 400-450 kg N/ha (313). In Britain, the most progressive dairy farmers are regularly using 200-300 kg N/ha each year (76, 213). The main reason is because in these countries many studies show that in general there is a linear response to nitrogen applied up to 300 kg N/ha over the year and a declining curvilinear response thereafter (129). For the first 300 kg N/ha, it can be expected an increase of 22-25 kg/ha for every kg N applied, and decreasing to below 10 kg/ha for higher quantities of N fertilizer (213). In Australia, a response of 20 kg/kg N applied up to a rate of 280 kg N/year have been reported (167).

As it was commented for Italian ryegrass, the yield of perennial ryegrass is also greatly influenced by the number of harvests and by the height of stubble. Increasing the frequency of cutting progressively depresses yield, although the quality of the forage remains high (129). In Galicia (341), average yields of 11 t/ha with frequent cutting and 15.3 with 3-4 harvests per year. Other results (250), in 1978-79, gave average yields of 7.64 t/ha for 4 different foreign cultivars with two levels of N (120 and 360), while a local ecotype produced 8.64 t/ha. This local variety differs from the imported central-European cultivars in that it has a better fall and winter growth and its yield is equal or superior to theirs.

In the regional variety test conducted in different locations of northwestern Spain in 1979-80, the best variety (C1, experimental Galician ecotype) gave at Grado an average yield of 11.43 t/ha, with 200 kg N/ha/year, and with a mean of 6 harvests. With the same management, the yield was 12.22 t/ha at Mabegondo and declined to 8.86 t/ha at Puebla de Brollon, which has a more severe climate with cold winters and hot dry summers (107).

In England, NIAB trials showed that for the variety S23, perennial ryegrass yields ranged from 13.9 to 11.7 t/ha for the first year swards in several locations, while the second year yields ranged from 9.5 to 11.3 t/ha (241). Other trials in Britain showed optimum annual yields for different areas from 5.2 t/ha in dry areas to 13.3 in wet and warm areas (241). According to Spedding and Diekmahns (287), most reported annual yields for perennial ryegrass on fertile lowland soil under a sequence of relatively infrequent cutting have been around 10.0 t/ha in Britain. Higher yields have been presented under cutting management compared with grazing in Britain. Jackson and Williams (147) reported a net growth yield of 5.56 to 9.0 t/ha with cutting compared with 3.0 to 8.69 t/ha of grazing with a 200 kg N/ha fertilization rate. Other results with 400 kg N/ha were 11.99 to 8.33 t/ha and 4.24 to 8.82 t/ha with grazing and with 600 kg N/ha, the yields were 12.2 to 7.87 t/ha and 9.05 to 4.20 t/ha with grazing.

In Holland, yields of 13.1 t/ha have been obtained with 4 cuts and 160 kg N/ha and with 8 cuts and 400 kg N/ha. Other results showed 16.2

t/ha with 4 cuts and 320 kg N/ha and 8 cuts and 640 kg N/ha (313).

In France, the N fertilization recommended is about 160 kg/ha for the early cultivars and 250 to 300 for late cultivars (145). In the northwest area of the same country, the 3-year average was 16.4 t/ha with 400 kg N/year. If N was reduced to 200 kg N/ha, the yield was 14.06 t/ha and without N, only 4.43 t/ha were obtained (20). In Oregon (U.S.), certain varieties of perennial ryegrass harvested from 3 to 7 times a year produced about 11.5 t/ha (89).

Crop quality As with all the grasses, the digestibility of herbage declines with maturity, and the same trend is followed by the N content, although this latter varies much and depends on the N available in the soil. Leaf proportion decreases with forage age and so does protein content, decreasing from about 18% at initial vegetative stage to 8% at flowering and the aftermath is about 13-18%. On the other hand, the digestibility of the organic matter declines from 83 to 63% and the aftermath is about 75-78% (145). For studies in Holland (313, 329), fertilizing perennial ryegrass with different amounts of N from 0 to 518 kg N/ha showed an increase in CP from 1.39% to 2.88% with increasing N fertilization, although the benefit of high CP is doubtful because the N needs of the dairy animal are not that high.

Frequent cutting has been shown to yield higher quality forage than less frequent management. Spedding and Diekmahns (287) reported that with monthly cutting, dry matter digestibility remains consistently high (75-78%) with a CP of about 12%. With less frequent cutting, higher yields of dry matter are attained, but its digestibility was reduced to a 64-73% and the CP content to 10%.

Commenting on the paper by Aldrich and Dent (3), Spedding and Diekmahns (287) wrote that for early heading cultivars dry matter digestibility at 50% ear emergence is usually about 75%, after which stage the digestibility falls by approximately 0.5% units per day, reaching 70% digestibility 12 to 14 days later. However, some cultivars gave digestibility values different from those expected from a knowledge of their heading date. For example, the cultivar Reveille heads within a few days of S24 but shows a consistently higher digestibility in its primary growth. Spedding and Diekmahns (287) also reported that for conservation purposes, a dry matter digestibility of 70% gives a feed of reasonable quality without too great a sacrifice in yield. The regrowth also may have 70% digestible dry matter. Other English papers, reported dry matter digestibilities from 70.7% to 82.1% with an average of about 75% for varying dates of cutting (334).

Wilman et al. (333) compared perennial and Italian ryegrasses, and they found that at an early vegetative stage the rate of digestion appeared to be higher for Italian than for perennial ryegrass. The rate of digestibility declined with increase in interval between harvests from 3 to 10 weeks (67.3% to 59.6% IVOMD). The values decreased slightly with extension of the interval beyond 5 weeks.

Other reports in Scotland (299) showed that the spring IVOMD decreased from 75% by the end of May to 55% by the end of June, grazing or mowing delayed the decrease in digestibility.

Research conducted in Australia (193) with perennial ryegrass reported mean dry matter digestibilities of 64.7% with a range from 56.7 to 74.0%. On the other hand, the mean N content was 3.26% with a range of 2.0 to 3.64%. The ADF was about 25.8%.

In other work with plant fractions (164), digestibilities of dry matter of 62.5 to 67.2% for the stems and 66.9 to 67.7% for the leaves have been reported. The N content of stems was between 2.7 to 3.4% and the leaves 3.4 to 3.8%. Finally, they had ADF values of 30.1 to 34.4% for stems and 27.3 to 30.8% for leaves.

Orchardgrass or cocksfoot

It is a perennial bunch-type grass, with slow establishment compared with ryegrass. It is one of the most deep rooting of all grasses and therefore the species is reputed to be drought resistant, though growth is certainly retarded by drought conditions. For these reasons, orchardgrass shows a better growth during the summer compared with ryegrass which can extend a little the grazing season.

Some Australian cultivars (167) persist well in areas where the annual rainfall is as low as 432 mm, providing the winter rains are adequate. It does not become completely dormant in the summer if moisture is available and can survive dry summers better than most European types. It is cold sensitive at the seedling stage but becomes cold resistant in latter stages of growth. It normally has a good persistence.

Many studies (3, 37, 258, 287) have found that orchardgrass compared with ryegrasses is lower in quality at similar stages of growth, and at least in Britain (128) less productive than perennial ryegrass when harvested at stages of growth of equal digestibility. These characteristics have contributed to the steady decline in cocksfoot in recent years in that country.

In the U.S. (150), orchardgrass has spread through a large area of the country and occupies an important place as a cultivated grass for hay and pasture.

Production, management and fertilization   Like the ryegrasses, orchardgrass is very responsive to N applications, and like the previous grasses, frequent cuttings decrease yields.

In Galicia, some research has been done in orchardgrass breeding (250). The improved local ecotypes have shown improved fall and winter growth, mainly in the milder climates. These local cultivars (VS3, F3) yielded equal or more than some selected foreign cultivars (S.26, S.37, Chantemille). With 170 kg N/ha, the two-year mean yields were 7.42, 6.67, and 4.66 t/ha at three Galician locations. Another experiment at Mabegondo with 250 kg N/ha gave higher yields in 1979. The cultivar VS3 gave 11.17 t/ha and S.37, 10.08 t/ha.

Other Galician results are reported in the official variety test (107). The best cultivars gave a two-year mean yield (1979-80) of 12.66 t/ha at Grado and 9.83 at Puebla de Brollon. One of the most productive cultivars was Napier of Iowa origin.

In Bretagne (France), Coppenet and LeCorre (51) found cocksfoot yields of about 8.00 t/ha. Also in France (20), a large response to N has been reported in three different locations of the country. Using three different N rates (0, 40, 80 kg/ha) after each cutting with 5 to 6 cuttings per year, the yields were between 2.13 to 5.32 t/ha for 0 nitrogen, 8.6 to 11.12 t/ha for 40 kg N, and finally 11.43 to 13.00 t/ha for 80 kg N.

Spedding and Diekmahns (287) in Britain presented yields of 11 t/ha from plots of cocksfoot irrigated and cut monthly. They also reported other works in which the average yield for 12 cultivars with three years and high level of fertilizer input was 9 t/ha.

In the U.S., Jung and Baker (150) commented that at high rates of N, orchardgrass is among the most productive of the cool-season grasses and that hay yields of 13.5 t/ha can be expected when orchardgrass is properly fertilized and with favorable weather. These yields can be reduced as much as 50% in years of drought. Jung and Baker (150) also quoted the research done by Washko et al. (1967) in West Virginia. They wrote that "if soil fertility is low, a large proportion of the total production occurs in the spring, whereas at high fertility levels production is well-distributed throughout the growing season. Aftermath production contributed from 33 to 66% of the total production when split applications of fertilizer are applied."

Other U.S. reports show a dry matter production of about 11 t/ha with 168 kg N in Indiana (101) and a maximum yield of about 15.51 t/ha with 670 kg N, also in Indiana, although half this amount of N gave 14.22 t/ha (75). In Iowa, Frank and Pesek (91) concluded that N in excess of 200 kg/ha/year is required for economic yields. They obtained higher yields (7.55 to 9.06 t/ha) with 270 kg N/ha compared with 540 kg N/ha.

Crop quality It has been observed by different authors (3, 195, 198, 258) that the ryegrasses are generally more digestible than orchardgrass, not only for the first spring growth but also for their regrowth (258). Aldrich and Dent (3) reported that the orchardgrass S37 was always more than 5.5% less digestible than the perennial ryegrass S24, although both had the same date of heading. A similar pattern was followed by the cultivar S.345, whose yield at 70% digestibility was barely two-thirds that of many of the ryegrass varieties.

Like the ryegrasses, as the orchardgrass advances from the vegetative to reproductive stage, the digestibility and the protein content decrease while the cell wall components increase. Jung and Baker (150) reported that at the vegetative growth stage, orchardgrass approaches the feeding value of alfalfa, whereas at the full bloom stage, it has approximately one-half the value. Several papers have been published about orchardgrass quality and many of them in the U.S.

In Scotland (United Kingdom), a study showed a yield reduction of 41% in mid-June for the crops grazed or mowed from January to May compared with the undefoliated crop (299). However, the digestibility values of the defoliated cocksfoot plots were significantly higher than the undefoliated throughout the experimental period (73 vs. 67% digestible by the end of May and 56 vs. 47% by the end of June, respectively). However, the total production of digestible organic matter per ha was higher for the undefoliated plants. Also in England (287), the digestible values obtained for cocksfoot frequently defoliated and kept in leafy condition varied between 68% and 79%. French data showed a decline in organic matter digestibility, from 80% at the vegetative stage to 58% at flowering for the first cutting, while the regrowths were about 72-74% (145).

Some results obtained in Canada comparing orchardgrass with other grasses found that the IVDMD of the crop decreased from 60.8% at vegetative stage to 42.7% at post-flowering stage (255). Another Canadian paper reported also a drop in IVDMD from the vegetative to early seed stage. At the vegetative stage, the IVDMD was about 74-79% while at the seed stage it was only 51.8-58.3% (217).

In the U.S., Sprague and Taylor (288) obtained increasing CP content of orchardgrass with increasing levels of N fertilization at the same growth stage. At the boot stage, the CP was about 11% for 28 kg N/ha, and 25.7% for 390 kg N/ha. While at the bloom stage, the means were 8.5% and 19.8% for 28 and 390 kg N/ha, respectively.

A different paper reported values of 59.6% IVDMD and 11% CP for orchardgrass harvested at flowering (285). Similar results were reported in Alabama where orchardgrass had a mean IVDMD of 58% (230). Working with orchardgrass hays in Arkansas, Stallcup and Raques (291) showed for the prehead crop the following values: 24.9% CP, 30.2% ADF, and 60.2% IVDMD, while at the late cut, the values were 12.6% CP, 41.1% ADF (extremely high) and 52.1% IVDMD. The same authors (290) presented the following values in a different paper: prehead orchardgrass, 15.1% CP and 36.5% ADF, while at mature stage, 10.8% CP and 41.4% ADF.

Legumes, general comments

The two legumes that are going to be examined, red and white clover, are normally associated with grasses while alfalfa, at least in Galicia, is normally seeded alone. However, it appears to be more interesting to study first the clovers alone, without any companion crop, as was done with the grasses and dedicate a final part to the study of the mixtures.

Although herbage legumes are subject to the same environmental factors as the grasses, there are a lot of differences between the two groups of plants in response to these factors. It is well-known that legumes do not generally require N, but they need adequate P, K and Ca. They are also intolerant of shade and thrive best under conditions of high light intensity. Although the majority of clovers are palatable, and have a high feeding and digestibility value, they are not normally as productive as the grasses.

Red clover

It is a short-lived perennial, and easy to establish from seed on a wide range of soils. Normally, it does not live for more than two years, but it can last three or four depending on the management, cultivar and diseases.

Red clover is the most popular legume among Galician farmers because of its rapid establishment and the high quality of its production. Red clover has an upright growth habit and is normally harvested for conservation although some of the more persistent of the improved strains could be useful for grazing (180). Red clover is a plant which grows best under moderate summer and winter temperatures with adequate moisture (300). It grows at temperatures between 7 and 35 C and there are cultivar differences in winter hardiness (84).

Application of N has been shown to reduce nodulation in red clover because N fertilizer taken up by the plant merely substitutes for the atmospheric N. However, exceptions have been found mainly on acid soils (pH less than 5.5) where nodulation is poor (287).

Production, management and fertilization The attraction of red clover is its high protein content and a yield which approaches that of grasses receiving high dressings of N fertilizer. Its yield is about (in Britain) 20% less than alfalfa, but in contrast it can be grown on practically all soils with no problems of rhizobial inoculation (128).

Some results obtained in Galicia gave as an average for 25 cultivars 15.47 t/ha of dry matter (341). In a different experiment comparing red clover, Italian ryegrass and their mixtures with 5 nitrogen rates, Piñeiro and Perez (249) obtained yields of 18.5 t/ha for a two-year mean of red clover. Their results did not show any kind of yield response to the N application, although the number of weeds had a tendency to increase with higher N inputs.

The cultivars used in Galicia are mostly of foreign origin; however, some improved ecotypes from nearby areas of the region have been shown to give higher production than some well-known foreign cultivars. In a comparative study, the improved ecotypes yielded (mean of two years) 10.54 t/ha compared with 9.63 t/ha for the imported cultivars. Other results have been reported (251), in which the mean of 37 cultivars was about 11.7 t/ha in three different locations.

French experiments with red clover report yields of about 10.9 t/ha at 800 m of altitude and 12-13 t/ha at lower locations (204). In Scotland, the average three-year yield for the best cultivar in an experiment where red clover was mixed with grasses was 10.2 t/ha (139). In a similar experiment in Northern Ireland (163), red clover with three harvests yielded 14.6 t/ha for the first year and about 10.00 t/ha for the second year. Also in that area, McBratney (190) reported a yield of 13.2 t/ha for the best cultivar in the best year in a four-year experiment. In England, Camlin (38) presented a three-year mean yield of 11.5 t/ha in a red clover monoculture. In the U.S., data from Wisconsin show a single harvest yield of 5.18 t/ha at the green-seed pot stage. Other results in Wisconsin gave 4.90 t/ha for red clover harvested for hay (284). In Kentucky (6), red clover breeders reported 6.05 t/ha for the best cross compared with 5.26 t/ha for the best check commercial variety.

Crop quality There are several studies on the forage quality of red clover. In general, it has a high protein content and a high digestibility and both decrease when the plant approaches maturity. For the best compromise between forage quality and yield, red clover sbould be harvested at the prebloom to early bloom stage (128, 302). Protein content declined from 28 to 14%, whereas dry matter yields increased from 933 to 7,105 kg/ha with advancing maturity from the vegetative to full bloom stages (302). In England, broad red clover has been shown to have a dry matter digestibility of about 75% in the spring, and at the late-flowering stage the red clover cultivar S123 can be as high as 80% (287).

Spedding and Diekmahns (287) also reported a work in which, with 3 to 4 cuts a year, the total dry matter yield was about 9,500 to 11,000 kg/ha with a digestibility of dry matter ranging from 75% at the early cuts to 61% at the late harvests, and a crude protein content declining from 25.0% to 17.5%. Also in England, Camlin et al. (38) obtained CP contents of 27.3% in first spring cuts. McBratney (190) found that the four-year mean of several cultivars had a digestibility of 68.23% with a CP of 14.3% and the samples included also weeds.

Comparing several forage species harvested at the first flower stage, Smith et al. (285) found that red clover had higher IVDMD (75.9%) and CP (19%) than alfalfa and sainfoin. In studying the changes in composition of the regrowth after August, Collins (49) obtained nitrogen contents from 4.06% for young regrowths to 3.12 for older regrowths with respective IVDMD values from 81.4% to 67.3% and the ADF from 15.6% to 24.9%.

White clover

White clover is probably the most world-wide distributed forage legume for pasture in the temperate zones (northwest Europe, New Zealand etc.). In the U.S., it is found in the humid eastern half of the country, in the Pacific Northwest, and in irrigated pastures of the intermountain region (170). White clovers are divided into three groups according to leaf size, ladino or medium large leaved white clover, common or medium small leaved and wild or small leaved (180). Normally, the ladino types outyield other varieties in the early years after sowing, but are not as persistent as the other two types.

In Britain, the medium small leaved cultivars S100 and Huia are widely used for general purposes, while the ladino type is more suited to light grazing with occasional cutting and survive better when sown with grasses receiving some N fertilization (128). White clover is normally used to provide a source of N for a sown companion grass, and it yields well in the mixture and produces a herbage rich in protein and minerals and of high digestibility.

White clover has a higher temperature requirement than the normal temperate grasses (optimum temperature about 24 C vs. 18-21 C for perennial ryegrass) and most of its herbage production comes in late summer and autumn. However, the plant is more sensitive to dry weather than grasses, and it needs an adequate supply of soil moisture for high yields (118).

<u>Crop management and production</u> Most white clover trials have been carried out in the presence of companion grass, and there are very few published data relating to a pure stand of white clover.

In Galicia, a three-year mean of 6 cultivars was 8.1 t/ha with Huia the most productive with 9.4 t/ha. In another test with 13 cultivars in 1973, the average yield was 8.87 t/ha, with S100 the highest yielding with 10.15 t/ha (341). Other mean yields reported at three locations of northwestern Spain were about 8.10 t/ha for 24 cultivars

(251). In a different study where an improved local variety was compared with Huia and California, the local ecotype was equal or superior to the foreign ones, yielding 9.43 t/ha. Huia gave 9.39 t/ha and California 8.48 t/ha (250). All these yields are normally lower than that obtained with red clover.

In Britain, Spedding and Diekmahns (287) report that without irrigation, white clover can yield between 6,500 and 8,650 kg/ha in a normal to wet season. However, if a dry summer follows a late spring, it may yield less than 4,000 kg/ha. In Australia, high quality forage with annual yields of 7,840 to 13,440 kg/ha have been recorded from clover grown under conditions of favorable nutrient and water supply (167).

In the U.S. at North Carolina, the production of white clover was compared with alfalfa with and without irrigation. During the first year, they obtained 5.53 t/ha for the white clover in irrigated conditions and 4.64 t/ha in nonirrigated plots. However, it did not have adequate persistence because the next year's yields were about 1.60 t/ha. In that experiment, alfalfa yields were a little higher than those of the clover (320).

Crop quality The main characteristic of white clover, apart from its lower yield, is its capacity for maintaining high digestibility with increasing maturity. At any age, white clover is more digestible than red clover, alfalfa, sainfoin, etc. It is well-recognized that the plant improves the feeding value and quality of a grass pasture.

The digestibility of white clover in the spring is very high and values of over 80% dry matter digestibility have often been recorded and young plants during the growing season have similar values (287). They also reported CP contents between 22.5 to 28.3%. Another study in Britain (64) with three cultivars of white clover harvested from the beginning of May until July reported N contents of 4.57 to 4.91% from the first cut and this level regularly decreased to 2.80 to 3.22% for the late cut during mid-July. On the other hand, the digestibility of the dry matter decreased from a little higher than 80% to about 70%. Wilman et al. (333) obtained values of 73% IVOMD at the beginning of May and of about 63% by July.

Kühbauch (160) in Germany compared the digestibility of leaves and stems of white clover, red clover and alfalfa for the first and second growth. He found that the IVDMD values for white clover stems and leaves were higher than for the other crops. The larger differences were for stem quality and red clover was the least digestible plant. The values presented for white clover leaves were 75.7 to 78.8% for the first growth and 75.7 to 77.5% for the second, and the values for stems were respectively 76.6 to 84% and 72.3 to 79.4%.

<u>Alfalfa</u>

Alfalfa is a worldwide distributed leguminous plant that originated in southwest Asia. It is well-adapted to a wide range of climatic conditions. Germination is minimal at temperatures below 10 C or above 35 C, and the most favorable temperature for seedling emergence is about 25 C (29). Alfalfa grows extremely well in dry climates on irrigated fertile soils. It is highly drought resistant but goes into dormancy during drought periods and resumes growth only when moisture conditions become favorable. Its ability to withstand drought is attributed to its deep root system (113). Although there are differences among varieties, an alfalfa crop requires between 800 and 900 mm of water (151). In some areas of Australia, the plant is grown with less than 300 mm of rainfall (167).

Alfalfa is also adapted to a wide range of soil conditions and does best on deep loam soils with porous subsoils; however, it is well-known that this leguminous plant is one of the most sensitive crops to soil acidity. This is the main reason why the crop is not popular in Galicia, where, as it was stated in an earlier section, soil acidity is a very common situation in the region. Under most situations, a water pH value between 6.5 and 7.5 appears ideal for maximum alfalfa production (264). In a soil with low pH, lime dressing and inoculation is necessary. Since ancient times, the value of alfalfa as a soil-improving crop has been known, and it is used extensively not only for its feeding value, but for its beneficial effect on succeeding crops. Conservative estimates of the amount of N fixed are 85-100 kg N/ha (35).

Alfalfa is also well-known for its excellent feeding value. It is used mainly for hay, but it also is used for pasture and silage. The importance of the crop has been reflected in the publication of several monographs dedicated to alfalfa (29, 157, 199, 283).

<u>Production, management and fertilization</u> The production of the crop can vary much depending on the area where it is grown. Temperature,

rainfall, soil, management, varieties etc. are important factors that influence the final yield. As with the other herbage species previously examined, the total dry matter yields of alfalfa are very dependent on the management, with generally higher yields with less cutting frequency, although the forage quality goes in the opposite direction (113, 157, 287). It is generally agreed that in harvesting alfalfa for hay, the highest yield of nutrients is usually obtained at near 10% bloom (283), and the crop should be harvested at this stage (113, 199). When alfalfa is used for pasture, normally it is associated with grasses, but either with grasses or alone, the evidence indicates that the crop requires a rotational grazing system with about a 40-day recovery period (137, 146, 315). Most research indicates that, at least in winter cool areas, autumn recovery growth must occur before a killing frost to maintain stands (113, 315).

In Galicia, alfalfa is grown successfully in a few areas, normally the ones with higher soil pH. At Mabegondo, Yepes et al. (341) grew alfalfa at a pH of 5.8. In a variety trial, they obtained yields of 17.8 t/ha for the best varieties under rainfed conditions. The better yielding varieties were of the Flamande-type. The U.S. varieties Talent, Caliverde, Vernal, Ranger, and Lahontan were generally among the least yielding and produced between 12.4 and 15.2 t/ha. The persistence of the crop in those conditions was about 3 to 4 years. An interesting point about alfalfa in Galicia is that its production is better distributed during the season than most forages, and is able to produce some forage during the summer.

In France, several reports presented dry matter yields of about 15 t/ha for alfalfa in rainfed conditions (137, 216). In Britain (287), the Flamande type varieties have consistently yielded at least 10% more than other types. This higher yield is mainly due to earlier growth in spring and later growth in autumn. Yields can vary widely between sites, but at the most favorable sites the annual yield can be well in excess of 10,000 kg/ha. Speeding and Diekmahns (287) also reported yields in other trials with cultivars of the Flamande type ranged from 8.40 to 17.20 t/ha with an average of about 12.00 t/ha.

In Australia, Matheson (189) reported yields of 6.16 t/ha under dry land conditions, and 22.40 t/ha for irrigated hay stands. In the U.S., yields vary greatly depending on the area. Some results in Iowa (229) show yields of 15.7 t/ha. In Wisconsin, yields of about 10 t/ha have been presented (275). In California (81), yields of 19.56 t/ha and higher have been obtained.

Alfalfa is a very sensitive crop to low pH, and also requires a plentiful supply of available calcium. For this reason, liming is a common practice in many areas. In Galicia, $CaCO_3$ applications of about 3 t/ha have been shown to be enough for clover establishment in poor soils (202), and this amount should be sufficient for alfalfa. Alfalfa also does best when P and K are readily available, and to maintain high yields it is necessary to increase maintenance applications, especially of K (113). In France, 150 to 200 kg/ha of P_2O_5 are recommended at seeding, and 80 to 100 kg P_2O_5/ha and 200 to 250 kg K_2O/ha for maintenance (216).

Crop quality In general, there is a negative relationship between yield and quality. Numerous observations have been reported on the decrease of protein and digestibility content and an increase in fiber and lignin with advancing maturity. As the date of cutting is delayed, the yield increase is mainly due to the stem with a decreasing leaf to stem ratio which reduces digestibility and protein content and consequently the feeding value of the plant (14, 160).

In Britain, Spedding and Diekmahns (287) concluded that since alfalfa does not tolerate frequent defoliation, its nutritive value at early growth stages is of little practical significance. Compared with other herbage plants, the digestibility of the alfalfa even in early spring is not high, being only about 75% at the beginning of the season.

In the U.S., Barnes and Gordon (14) in Indiana reported digestibilities of a little higher than 70% at the vegetative stage which then declined to about 63% at full bloom, and the CP content decreased from about 28% to 20%.

In Pennsylvania, Jung et al. (153) reported IVDMD percentages from 66 to 82% depending on the yield and date of cutting and at the same time, the CP ranged from 29 to 20%. Burns (33) presented dry matter digestibilities of more than 70% at the vegetative stage and about 50% at full bloom. Stallcup and Raques (291) in Arkansas presented values of 26.8% CP, 24.8% ADF and 69.8% IVDMD for prebloom alfalfa, compared with 26.5% CP, 33.0% ADF, and 58.9% IVDMD at the 1/10 bloom stage for alfalfa hay. In a different experiment, they obtained for prebud alfalfa 21.3%

CP and 41.7% ADF, and when the alfalfa was cut at the 1/10 bloom stage, the values were 18.3% CP and 44.1% ADF. Other values have been published by Smith et al. (285); they obtained 66.5% IVDMD and 18% CP at first flower. These values were lower than those obtained with red clover.

In Wisconsin, Collins (49) also compared alfalfa and red clover, but during the autumn. Depending on the year and cutting date, the values for N content were 3.30 to 4.40% for ADF, 19.1 to 28.5%, and for IVDMD 67.7 to 81.3%. In Minnesota, in a harvest management study, Sheaffer (275) obtained mean season CP values of about 21% for early harvests and about 18% for later cuttings. At the same time, the IVDMD values were respectively 63.26% and 59.9%. In Iowa (229), in an alfalfa cutting study, ADF values of 34.9 to 36.2% were obtained at 45 day intervals, while with more frequent harvesting (32 to 35 day intervals), the ADF were 30.3 to 30.9%. In Canada, Mowat et al. (217) reported IVDMD percentages of about 76 at vegetative stage and about 55.6-60.9 at early seed.

Grass-legume mixtures

The use of grass-legume associations for herbage production is a very important topic that has been the object of much research. The renewed interest in this subject is mainly because of the role that legumes represents in nitrogen savings.

It has been shown in the previous sections that grasses normally respond very well to N fertilization and that heavy applications of this element generally result in high herbage production. On the other hand, it is well-known that legumes do not respond to nitrogen and that their forage yields are normally lower compared with N-fertilizer grasses. However, the opposite trend is generally true at low levels of soil nitrogen. Grass-legume associations attempt to take advantage of both facts with a compromise of obtaining large herbage yields with little or no use of nitrogen. In certain countries of Europe, as was reviewed, high herbage yields are based on heavy applications of nitrogen on grasses without legumes. On the other side, in areas like New Zealand, sward productions rely on white clover stands. The direction to take for a particular region will depend greatly on economical and geographical aspects. However, with the current concern on energy savings, it appears that mixtures are going to play a very important role.

Apart from N economy, other factors make mixtures attractive. The addition of legumes generally results in better forage quality as well as better production distribution throughout the year (19, 20, 118, 137). On the other hand, grass-legume mixtures may need a more careful management than grasses alone. It is generally accepted that grasses have a competitive advantage over legumes and therefore tend to dominate the mixture (118, 128) and sometimes can cause the disappearance of the legumes.

Two main characteristics of the association are evident from the research:

(a) Large herbage production with less N than seeding grasses alone with moderate amounts of N fertilization.

(b) Grass production predominates during the spring, whereas the main yield of the legume occurs later into the summer.

There are many types of grass-legume associations, and they change from one region to the other according to the adapted species, management, etc. In this review, only the association with similarities to those seeded in Galicia will be examined.

Utilization and persistence of the mixtures According to the species used, it is possible to make the distinction between short term and permanent mixtures. In the first case, the species are normally annual or biannual, and in the second they have greater persistence (6 to 7 years or more). A classic example for the first type is the association of Italian ryegrass with red clover, and for the second type is the perennial ryegrass with white clover. Those prairies also are examples of types of pasture utilization. Italian ryegrass-red clover is used chiefly for conservation, while perennial ryegrass-white clover is a mixture well-suited for pasturage (145, 149, 330, 341).

Short-term associations Although there is not always a clear distinction between short- and long-term associations, a certain kind of division, although imperfect, will help to clarify the material that is going to be reviewed.

In Galicia, Piñeiro and Perez (249) worked on the effect of nitrogen in an Italian ryegrass-red clover mixture. They used 5 rates of N from 0 to 240 kg N/ha. They concluded that the mixture without any nitrogen yielded as much as the Italian ryegrass with 200 kg N/ha. The average mean yield of two years for the association without N was about 18.5 t/ha. Increasing N fertilization only changed the composition of the sward, but not the yield. They recommended that the use of N in this kind of prairie should be limited to about 45 kg N/ha at the beginning of spring and also that it would be interesting to study the effect of broadcasting 30 kg N/ha during September if an adequate stand of Italian ryegrass was present. In this experiment, Italian ryegrass production was mostly during the spring, while the red clover continued some production into the summer and fall.

As it was said earlier, the mixture with intermediate duration which is most popular in Galicia includes Italian ryegrass, orchardgrass, red clover and white clover. Because of its components, this association is very easy to establish. The idea of this mixture was to have a more persistent but also high productive mixture than the Italian ryegrass-red clover. Normally the first year of production is the highest and most of the yield is provided by the ryegrass and red clover, but in the following years, the ryegrass and red clover contributions decrease and after 2 years, most of the production is due to orchardgrass, at least when the sward is managed for conservation purposes. The productive life of the association is between 3 to 5 years.

These changes in sward composition and productivity are important subjects of study and have been reported in a symposium (43). It has been shown that normally there is a botanical change with age and that the general pattern is a reduction in the contribution of sown species.

This change frequently implies a yield decrease. In France, Huguet and Guy (137) reported mean values for the experiments in different locations of the country. The results show that red clover alone yielded 8.1 t/ha, which was less than that of Italian ryegrass with 250 kg N/ha (12.1 t/ha). The interesting point is that the association yielded 12.3 t/ha with only 125 kg N/ha, which is one-half of the fertilizer applied to the Italian ryegrass. Another French article reviewed the grasses-red clover associations (204). They presented results and yields similar to the previous paper. An Italian ryegrass-red clover association with 100 or 125 kg N/ha produced as much as Italian ryegrass alone with 200 or 250 kg N/ha. However, the N content increased from 1.44% for the ryegrass to 2.09% for the mixture. They also commented that most of the ryegrass production came during the spring, while the red-clover growth was better distributed throughout the year. They concluded that the management of this association is very difficult and that the red clover production was not uniform and thereby affects the forage quality of the herbage.

Several investigations have been done in Britain with mixtures of ryegrass and red clover. In Scotland, Frame et al. (90) compared red clover with a mixture of red clover and perennial ryegrass. They found that the associations yielded better, 9.5 vs. 7.5 t/ha, for the red clover alone. IVOMD also was higher, 75% vs. 64%, and CP contents were similar. Also, with this association in Northern Ireland, yields of about 14.5 t/ha were obtained for the first year and about 10.0 t/ha for the second year. The IVOMD of the mixture changed from 59.5% to

77.9%, depending on the date of harvest, but the normal values were somewhat around 65.67% (162). More recent studies in Northern Ireland (190) compared five cultivars of red clover grown alone and in association with perennial ryegrass, tall fescue and timothy with no N fertilization during a four-year period. The mean annual total dry matter and clover dry matter yields of the five cultivars were between 12.4 and 13.2 t/ha and between 9.8/79.7% of total dry matter yield and 10.6 (83.5%) t/ha, respectively, and the differences between clover cultivars were not significant. The IVDMD values changed with harvest dates and years, but they were between 56.3 to 72.1% for the red clover alone and very similar for the mixtures. Camlin et al. (38) studied in Northern Ireland the productivity of mixtures of Italian ryegrass and red clover. They reported that as an average over 3 years, the grass-clover mixtures produced 14.3 t/ha which was 75% of the yield of N-fertilized ryegrass (300 kg N/ha), 125% of the clover monocultures and 225% of the unfertilized ryegrass. The red clover contribution to the total dry matter of the mixtures averaged 45 to 60%.

Long duration associations These mixtures normally contain some of the following species: perennial ryegrass, orchardgrass, tall fescue, timothy, white clover and alfalfa. The most common Galician associations only include perennial ryegrass, orchardgrass and white clover (248).

In Galicia, Piñeiro and Perez (251) applied moderate rates of N (25, 75 and 150 kg/ha/year) to several orchardgrass-perennial ryegrass mixtures with and without white clover. They found that the presence of clover increased herbage yields by 21%, and that grasses without clover receiving 150 kg N/ha/year only produced 5% more than mixtures with clover with 25 kg N/year. In the same experiment, orchardgrass alone produced more (6.08 t/ha) than perennial ryegrass (5.6 t/ha); but when clover was added, there were no yield differences (6.9 to 7.0 t/ha). Orchardgrass was very aggressive towards white clover, while the perennial ryegrass was an excellent companion crop, as has been reported in other countries (19, 118, 128, 166).

Other research conducted in Galicia is related to the use of N in grass-legume mixtures. Gonzalez (106) applied varying amounts of N to a long-term sward composed of perennial ryegrass, cocksfoot, white clover and ladino clover. He found that up to 120 kg N/ha during the spring resulted in a production increase of about 20 kg dry matter/kg N, while 40 or 80 kg N/ha at the fall only gave 6 kg/kg N. The use of N resulted in a decrease in clover percentage in the sward. He concluded that if this type of mixture contains adequate clover, there is little advantage in using nitrogen because the prairie produces 9 t/ha without N and only 11.2 t/ha with 200 kg N/ha.

Reviewing the use of N in mixed prairies in Galicia, Gonzalez (105) recommended for pasture swards annual applications of about 90 kg/ha split in three times of application. If the prairie is mainly for conservation, he does not recommend more than 180 kg N/ha (also split) because if higher rates of N are used, the prairie will end up being a grass prairie and not a grass-legume association.

In France, associations made of perennial ryegrass, orchardgrass, tall fescue and white clover are the most common (19). Studying the use of N in these mixtures, Bernard and Boyeldieu (20) tried to find a compromise between N savings through the white clover and higher production by N fertilization. They wanted to know the best time for applying N, without hurting the clovers, and also to take advantage of the difference in the seasonal growth patterns of grasses and clovers. In a several-year experiment, they found that a grass-white clover sward without N produced between 7.2 and 14.5 t/ha, depending on the locations and years. White clover participation was around 73% of the total production. They wrote that it is difficult to give fixed rules for management because the participation of the clover is not predictable. However, they concluded saying that the equilibrium depends on the amount of mineral N fertilizer since each additional unit of N after a harvest decreases the percentage of white clover about 1 point. Another conclusion was that moderate amounts of N fertilizer after each spring cut increased the total herbage production while maintaining a white clover stand. In Atlantic climates, a 40 kg N/ha after each of the first three spring harvests can be considered a moderate fertilization. Applications of 80 kg N/ha only increase prairie production slightly compared with the 40 kg N/ha. Yields were about 16 t/ha for perennial ryegrass-white clover with 160 to 200 kg N/ha/year, and about 10.0 to 11.5 t/ha for orchardgrass-white clover which varied with location.

In Britain, many papers have been published about N effects on long-term mixed prairies but only a few of them are going to be presented. Cowling and Lockyer (54) grew 7 species or varieties of grasses and mixtures of 3 of them in pure swards and with white clover, with 4 rates of N fertilizer after each cut. They found that the effect of clover on the yield of timothy-clover mixtures was estimated to be equal to 60 kg of N/ha. They also found that the fluctuations in annual yields were greater with grass/clover mixtures than with grass swards receiving N. Reid (260) applied different N rates to perennial ryegrass-white clover mixtures. He reported that the inclusion of white clover increased the yields of dry matter and crude protein at a low nitrogen rate. On the other hand, the yield and responses of the grass-clover sward were not significantly different from those of the pure-grass sward at nitrogen rates above about 336 kg/Ha.

Laidlaw (162) studied the effects of moderate N fertilization in spring on swards of ryegrass-clover. He found a yield increase with N fertilization for all the treatments, with a greater response for the treatments without clover, and that the annual dry matter yields were lower in those without clover than in those of mixed swards at any given N level.

Wilman and Asiegbu (332) also studied aspects of nitrogen fertilization and cutting interval in perennial ryegrass-white clover swards. Their results show that increasing the interval between harvests increased the yield of white clover and generally did not reduce the proportion of clover in the total herbage. They also found that medium-leaved varieties of white clover respond better to less frequent defoliation than do the small-leaved types, and that they seemed more tolerant to the adverse effect of applied N than the smaller leaved varieties.

In New Zealand, Ball et al. (12), working on the influence of fertilizer nitrogen on grazed grass-clover pasture, reported a dry matter yield response to annual inputs of 112 and 448 kg N/ha. However, the clover was suppressed, particularly at the heavier N rate. The net fertilized yielded results of 18.2 t/ha and yields were increased 1.1 and 3.5 t/ha by the low and high inputs of nitrogen, respectively. They also concluded that the N responses were substantial during late spring-early summer where pasture growth rates were maximum, but only at the heavier rate of application. They obtained very little N response in late autumn-winter-early spring and a lack of responsiveness by the mixed pastures during the dry mid-summer.

In the U.S., there are no recent published data in which they use mixtures similar to the ones which have been examined. The main reason could be, as it was already expressed in a previous section, because normally the main herbage species used are basically different. However, in the U.S. papers, some type of similar associations have been investigated. In Tennessee, Fribourg et al. (93) studied the seasonal quality trends of the cool-season mixture orchardgrass-ladino clover. This association gave IVDMD values from about 70 to 75% in April to 55-65% in August which were always higher than the digestibilities provided by bermudagrass.

In Pennsylvania, Jung et al. (153) compared production and quality of two pastures, perennial ryegrass-alfalfa and orchardgrass-alfalfa, in order to find a suitable companion grass for alfalfa. They did not find significant differences in dry matter yields which were 12.5 t/ha for ryegrass-alfalfa vs. 12.0 t/ha for orchardgrass-alfalfa. The mean herbage crude protein concentrations were: alfalfa, 22%; ryegrass, 20%; and orchardgrass, 16%. The mean IVDMD was: ryegrass, 77%; alfalfa, 73%; and orchardgrass, 70%, with a respective range of 85 to 70%, 77 to 61%, and 82 to 66%. They concluded that adapted ryegrass-alfalfa mixtures offer substantial potential contributions to forage-animal production systems and economies.

Seasonal distribution of pasture production   Before ending the review of the literature corresponding to the pasture plants and their mixtures, a brief examination of a subject that has been already implicited while commenting on the herbage species will be done. The topic is the seasonal growth of pastures.

It is clear that the rate of growth for all grass and legume species varies during the year and that this growth depends on several limiting factors such as temperature, water, light, nutrients, etc. which interact with the species' own physiology. The differential plant growth of the components can cause variation in species dominance during various parts of the year in a herbage mixture. This variation can be enhanced or depressed by the management conditions.

Yepes and Piñeiro (340) wrote a paper about the seasonal growth of some herbage species. They reported that in Galicia, grasses gave most of their yield during the spring, some during the fall, and almost nil during the summer and winter. Piñeiro and Perez (248) in a different paper reported that production by mixed sward has two peaks, in Galician conditions, a large peak in the spring and a smaller one during the fall, while summer and winter productions are very small. Summer production is limited by hot dry conditions, while in winter, low temperatures restrict production.

In Britain, Anslow and Green (10) published a paper about the seasonal growth of pasture grasses. With their conditions, the production of pasture is limited mainly by the low winter temperatures. Their production curve is similar to that of the Galician one, with an important difference in that production continues during the summer. Their figure for production shows a high peak during the spring and a continuous decreasing slope until winter, although there is a small valley during the summer.

In New Zealand, several papers have been written about seasonal pasture distribution. Only one example is going to be discussed. In the west coast of the South Island, the distribution of pasture production is a little similar to the one reported in Britain. On the average, 5% of annual yield was produced during winter, 37% in the spring, 37% in the summer, and 21% in the autumn (214).

MATERIALS AND METHODS

Crop Rotations for the Production of Forages

Duration of the field experiment

The experimental plots were established during the spring of 1980, and the last harvest was done in the fall of 1983. The total duration of the experiment was 3.5 years, but because of some field problems, statistical analysis and practical reasons, only data for three years will be considered. For all practical purposes, the experiment started in the fall of 1980 and ended in the fall of 1983.

Due to some field problems, in one location, the available data for certain crops are only for two years. The details will be explained in the next sections.

Field experiments

Locations The field experiments were established at four locations with different climates (Appendix A) and soil type. This distribution should allow a better knowledge of the production potential of crops and geographical areas. The locations were the following: Arzua, Mabegondo, Puebla de Brollon and Puenterareas.

Arzua Arzua is located at the Parroquia of S. Esteban de Campo at 400 m of altitude in the interior part of Galicia. This place is the coldest of the four locations; its growing season was always the shortest and its soil was also the poorest (Table 3). The temperature and rainfall are contained in Appendix A.

Mabegondo It is located at about 100 m of altitude, and very near the coast. The climate is mild, not very cold in the winter and not very warm in the summer. This is the location of the Regional Agricultural Research Center; the climate of the area is presented in Appendix A, and the initial soil test in Table 3.

Puebla de Brollon In this place, the INIA (Spanish Institute of Agricultural Research) has a field station. Puebla is located in the very inner part of the region, having the most continental type of climate of our experimental sites. It is very warm and dry during the summer and cold during the winter. Its altitude is 450 m. The weather measurements are presented in Appendix A and the initial soil test in Table 3.

Puenteareas This town is located in the southwestern part of the region at about 10 km from the Portugal border and at a 90 m altitude. It has a mild climate during the winter and very hot and dry during the summer. The climatology is presented in Appendix A and the initial soil analysis in Table 3. At this location, the corn, but not the other crops, was irrigated one or two times during the summer, depending on the year and water availability.

Soil analysis In order to know the initial level of soil fertility, soil samples were taken before the establishment of the experiments during the spring of 1980. The results are shown in Table 3. The data are the mean of several samples (6 to 10) and each of these is a mixture of 5 to 10 subsamples which were taken at a depth of 0 to 25 cm.

Table 3. Initial soil analysis[a]

Location	Soil type	pH	OM (%)	P (ppm)	K (ppm)
Arzua	Sandy-clay-loam	5.40	7.86	6.46	74.20
Mabegondo	Silt-loam	5.56	3.15	44.80	294.50
Puebla de Brollon	Silt-loam	6.00	3.24	46.51	145.86
Puenteareas	Sandy-loam	5.66	5.16	46.83	157.31

[a]All chemical determinations, pH, organic matter, extractable phosphorus and extractable potassium cation exchange capacity and Al^{+++} were calculated using the current soil analysis methodology (235) (pH was measured using water solution, phosphorus was determined by the Olsen method, and potassium was extracted by neutral ammonium acetate).

The Arzua field site was located on an old permanent pasture and this could be the reason for its high OM content. The site at Puenteareas was previously occupied by a tomato crop, and the other two locations had been under a temporary pasture for several years. The pH values were, in general, a little acid. The highest and the best for cropping was for Puebla de Brollon. The organic matter contents were, for Galician conditions, high in Arzua and Puenteareas. As far as P is concerned, all the locations but Arzua, which had a very low P content, had an adequate level of this element. The soil content of K was high at Mabegondo, normal-high at Puebla de Brollon and Puenteareas, and low in Arzua. According to the soil test, Arzua was the only place where soil fertility differs greatly from the other fields.

To know the possible effects of the crop rotations and their fertilization on the soil fertility, soil samples of each plot were taken during the spring of 1983, before planting corn. The results for each location will be analyzed for possible differences among treatments and compared with the initial analysis of the samples taken in April or November of 1980.

Crop rotations

It has already been reported in the Literature Review that in Galicia there are several different crop rotations practiced and common mixtures of sown prairies. The crop rotations used in this experiment were the following:

Annual sequences -

1. Corn
2. Corn → rye
3. Corn → oats-vetch
4. Corn → Italian ryegrass (6 month)

Biannual -

5. Corn → Italian ryegrass (11 month) → forage rape

Pastures -

6. F_2 (2 year) → corn
7. F_2 (3 year)
8. F_6 (permanent pasture)

The four annual sequences are very popular in different areas of the region. In the rotation number 1, which had only corn, the variety used was normally a somewhat longer season variety than that seeded in the other rotations, because of the need to harvest the corn in time to plant the winter crops in those rotations.

The sequence of corn → Italian ryegrass is used very extensively in the southern part of the region but also in some other areas, mainly near the coast; and sometimes it has been promoted strongly by different agricultural organizations. In some areas of France, with similar climate, this is the most commonly used rotation (253, 256).

The corn-rye sequence is practiced throughout the region, but mainly in the interior parts, while the corn-oats is more common in the coastal areas. In this experiment, some vetch was mixed with oats to improve the quality of the forage.

The fifth sequence, corn → Italian ryegrass → rape, is a theoretical one that tried to imitate the most popular and typical Galician rotation which is

$$\text{corn} \rightarrow \frac{\text{rye}}{\text{wheat}} \rightarrow \text{turnips}$$

but with a forage orientation. For this reason, the rye and wheat for grain production were replaced with Italian ryegrass (12 month) and the turnips (difficult to harvest by machine) by forage rape. The type of prairie mixtures used in the comparison might not always be the best kind according to the research in progress, but they are among the most commonly used. The first mixture (rotations 6 and 7) was the so-called F_2, which is a temporary prairie composed of Italian ryegrass, orchardgrass, red clover and white clover. The second type is a permanent pasture, called F_6, and it contains perennial ryegrass, white and ladino clover.

Crop seeding and harvesting (philosophy of the procedure)

In any crop sequence where a crop has to be harvested to leave time for the next, there normally are some problems and some short periods of peak field work with not always a favorable weather. In those cases, some kind of compromise has to be taken and in this dissertation, the following criteria were applied.

(a) In all cropping sequences, corn was considered to be the most important crop; and when it was its seeding time, all other crops were harvested independently of their production and stage of growth. The reason is because corn is not only the most expensive, but also the most productive crop, and it has to produce as much as possible in order to be economically interesting. To make a more realistic field experiment, some crops were harvested as much as 20 or 30 days before corn. The reason was because the field work in the experimental plots can be done in a matter of hours, whereas with a farm situation, it can take days or weeks, depending on the machinery and weather.

(b) Fall always has been a critical period for seeding the winter crops and prairies. For this reason, although the variety seeded at each location was chosen to fit in the rotation, corn was harvested, at the latest, by the end of September independently of its moisture content.

These two points, a and b, can be summarized by saying that the seeding time always had priority over the harvesting.

(c) Having research fields distant from the central research center sometimes made it difficult, mainly during the fall, to harvest and seed the crops in a two-week period because of the frequent rainfall at this time of the year. In this situation, if some location had to be delayed, it was always Puenteareas, because it was the most distant from the Central Research Center (3 1/2 hours), and it had the mildest weather during the winter.

(d) An attempt was made to harvest each crop at the best stage for silage production according to the literature.

(e) During mild winters, certain crops grew very well, mainly oats and Italian ryegrass, and heavy posterior winter rains lodged the crops. In those cases, the plots were harvested and the final production included the addition of the winter cuttings and their regrowth.

(f) In a normal year, pastures and Italian ryegrass have most of their production during the spring, and they are harvested for silage once or twice and they are grazed for the rest of the year. This kind of management was imitated in the experiments. The control values from the spring gave an idea of the production during the other seasons.

Soil preparation

Before the establishment of the experiments in the spring or fall of 1980, all previous crops at the different locations were plowed under, disked several times, and finally rotary cultivated. After this initial field work, the soil preparation in the following years was basically done with a rotovator. This tractor-mounted implement was passed several times at its maximum depth burying the previous crop residue and the next crop's fertilizer except only one-half of the N. This kind of soil preparation is not usually followed in the region, but because of the plot size, 3.2 x 6 m, the rotovator was the most practical and almost the only implement we could use. Some agronomists (136, 281) believed that the long term use of this tool as the only field tool induces a soil pan in certain soils and destroys the soil structure and reduces crop yields. This may be true, but our experiment was a short-medium term duration, and we always tried to use the rotovator as deep as possible. Another point is that if any crop would have been affected, it would have been the summer crops, that is, corn, but not the winter crops, because at this part of the year there is plenty of moisture. A practical aspect of this possible problem is that the results might be conservative, which is always good in practical field research.

In Arzua during 1981, 1982 and 1983, we could not get a tractor rotovator, and the soil preparation was done by a two wheel tractor with a plow and rotovator. At Mabegondo and Puebla de Brollon in 1983, the soil was plowed before seeding the corn.

Agronomic aspects of the crops

Cultivar selection, plant population, row spacing, seeding rates, fertilizer rates, herbicides, planting and harvesting dates, etc. were based on known recommendations with adaptation to the conditions of this research. When the regional information was not available, the research reported in the technical publications about this particular subject was used.

The philosophy of the experiment was not to get the highest possibel yields in every crop, but to obtain normal yields following the current recommendations for each crop. For this reason, the amount of N fertilization employed might seem low, but many Galician farmers would certainly say that they cannot afford these quantities.

Cultivar selection   The varieties used were normally well-known commercial varieties used in the region. However, there were several exceptions. For oats, *Avena strigosa* and not *A. sativa* was chosen because it is the most common in the region. Very little forage rape is grown in Galicia, and the selection of the variety was mainly based on seed availability, even when knowing that some other varieties might be better.

Because of the climatological differences between Galicia and many areas of the country, there was not a known cultivar of rye similar to the ecotypes used by the Galician farmers. In this case, the variety Petkus-Kustro was selected because, although it has a different type of growth, the final forage yields are quite similar to that of the local ecotypes and the quality may be a little higher (175).

For corn, a choice of many hybrids was available, and the varieties used were adapted to each particular location. The variety of corn used varied from year to year, depending on the previous year's results, variety tests and seed availability, but we attempted to use similar types of hybrids each year.

The varieties, seeding rates and plant populations of the crops are presented in Tables 4 and 5.

Table 4. Varieties, seeding rates and plant poulations for the crop rotation experiment

Crop	Variety	Seeding rates (kg/ha)	Plant population (plant/ha)
Corn	(See Table 5)	--	100,000
Italian ryegrass	Tetrone	30	
Oats-	Saia	70	
vetch	*V. villosa*	50	
Forage rape	Blako	10	
Rye	Petkus-Kustro	130	
Prairies			
F_2			
Italian ryegrass	Tetrone	4	
Orchardgrass	Artabro	10	
Red clover	Alpille	1	
White clover	Huia	2	
	Total	26	
F_6			
Ladino clover	California	2	
Perennial ryegrass	Reveille	20	
White clover	Huia	1	
	Total	23	

Table 5. Varieties of corn in crop rotation experiment

Year	Location			
	Arzua	Mabegondo	Puebla	Puenteareas
1981				
Rotation 1	Domino 440	Domino 440	(EC22 x F14A) x A632	(EC22 x F14A) x A632
The other rotations	Horreo 330	Horreo 368	Star x EC22	Horreo 452
1982				
Rotation 1	Horreo 330	Domino 440	Horreo 453	Horreo 453
The other rotations	Horreo 330	Horreo 330	Domino 440	Domino 440
1983				
Rotation 1	Horreo 330	Domino 440	Domino 450	Domino 450
The other rotations	Horreo 330	Horreo 330	Domino 440	Domino 440

<u>Fertilization</u> The rates of fertilizer applied for each crop are presented in Tables 6 and 7, and the kind of fertilizer is shown below:

Element	Product	%
N	Ammonium nitrate	20.5 N
P	Superphosphate	18.5 P_2O_5
K	Potassium chloride	60 K_2O
Ca	Lime	50 CaO

Normally, the crops received a basal application of N, P and K and a top dressing of N fertilization, which for winter crops and prairies was during February at the beginning of the spring growth. Prairies also received a second N top dressing after the first cut of silage and a third at the beginning of the fall when, under Galician conditions, prairies resume their growth after the summer drought. Prairies also received an annual application of P and K at the end of winter (Table 7).

Corn also received a basal and a side dressing of N (Table 7). However, as it is shown in Table 7, the ratio of side-dressed N to basal N was not the same each year. Practical experience showed that in a dry spring or summer, it might not have rained enough for the N to have been used by the crop. It was thought that it was safer to include most of the nitrogen fertilizer in the basal application.

<u>Herbicides</u> The only crop that was chemically weeded regularly was corn. The preseeding herbicide application was a mixture of atrazine (1.5 kg/ha) and alachlor (3.5 kg/ha) of active product.

Rye was sprayed during 1981 with Mecoprop at a rate of 1-2 L/ha.

Table 6. Fertilizer application (kg/ha) for the forage crops in the rotations experiment

Crop	N	P_2O_5	K_2O	CaO
Italian ryegrass (annual rotation)				
Basal application	40	120	100	
Top dressing	30			
Italian ryegrass (biannual rotation)				
Basal application	40	120	100	
Top dressing	(30+40)			
Oats-vetch				
Basal application	30	100	80	1000
Top dressing	40			
Rapeseed				
Basal application	40	100	80	
Top dressing	40			
Rye				
Basal application	30	100	80	
Top dressing	40			

Table 7. Fertilizer application (kg/ha) for the corn and prairies in the rotations experiment

Year	N	P_2O_5	K_2O	CaO
	Corn			
1980				
Basal application	80	150	100	
Side dressing	60			
Total	140			
1981				
Basal application	100	150	100	
Side dressing	40			
Total	140			
1982-83				
Basal application	120	150	100	
Side dressing	20			
Total	140			
	Prairies			
1st year (seeding to fall next year)				
Basal application	30	120	100	1500
Top dressing (spring)	40+40			
Following years				
Top dressing				
Fall	40	--	--	
Winter	--	80	100	
Spring	40+40	--	--	

On this year, rye was reseeded because of the poor germination, and at the end of November weeds became a serious problem. During the spring of 1983 in Puenteareas, some plots of the prairies were invaded by <u>Rumex</u> ssp and Asulam at the rate of 1.2 kg/ha of active product was used, with very good results. However, it is known that this product depresses clover production. On every spring after the harvest of the winter crops, the plots that were to be planted to corn were treated with paraquat which killed the aftermath and facilitated seedbed preparation for corn planting. Some hand weeding was done when needed.

The most common and troublesome weeds in the experiments were:

Crop	Weed
Corn	*Cyperus sculentus*
	Polygonum persicaria
	Polygonum convolvulus
	Echinochloa crus-gallii
	Digitaria sanguinalis
Prairies and winter crops	*Stellaria media*
	Spergula ssp.
	Rumex ssp.
	Raphanus raphanistrum

Pesticides The initial idea was to avoid the use of insecticides, but during 1980, corn was heavily infested with soil insects, *Scotia* ssp., *Agrotis segetis* and *Anoxia villosa*. For this reason, it was sprayed with Phoxim 10%. Severe infestations with worms were also observed in Arzua during 1981 and 1983. In general, there were insect problems in corn during the duration of the field research.

Bird damage In this area, birds always are a problem for the corn seedlings, and in these studies they were worse because of the use of small plots and seeding a week earlier than most farmers of the area. The 1980 corn crop in Arzua was devastated and the one in Mabegondo was very damaged. On the rest of the years, Arzua and Mabegondo corn plots were covered with plastic nets.

Seeding and harvesting methods

All crops but corn were broadcast seeded. Then, the seeds were covered and pressed into the soil with a roller. Corn was seeded in 80 cm rows at an initial population of 120,000 plants/ha with a hand planter. Then, when it was 20-40 cm tall, it was hand thinned to the approximate planned population.

Harvesting   All crops but corn were harvested with a 1.20 m head mower. Corn plots consisted of four or five rows of corn and the two central rows were harvested for yield determination. The ears and the rest of the plant were weighed separately and the number of plants counted for density determination.

Dates of seeding and harvesting   The seeding dates for all crops are presented in Table 8. Because of bird and worm problems, some corn reseeding was done almost every year to assure the planned density. During the spring of 1980, prairies were seeded at Arzua and Mabegondo. The dates were April 21 and 23, respectively. Spring prairie seeding is not as common as fall seeding, but these were seeded in order to get more information.

The variations in the dates of planting were mainly weather related. Spring and fall are normally rainy seasons and sometimes it was very difficult to have 3 to 5 consecutive days without rain. For example, the spring of 1981 was drier than normal; however in 1983, during the April to May period it rained 30 days in a row.

Table 8. Dates of planting

Location	Year			
	1980	1981	1982	1983
		Corn		
Arzua	May 2	June 2	May 17	June 9
Mabegondo	May 8	April 24	May 3	May 30
Puebla	May 9	May 5	May 13	June 7
Puenteareas	--	April 23	May 7	June 9

Location	Year		
	1980	1981	1982
		Winter Crops and Prairies	
Arzua	October 2	September 30	October 23
Mabegondo	October 1	October 5	October 20
Puebla	October 7	October 1	October 20
Puenteareas	October 20	October 20	November 2

Climatological data

The climatological data for each location from 1980 to 1983 are presented in Appendix A.

Field sampling and dry matter determination

A sample of approximately 500 g from each replication was taken from the green forage harvested from each plot. The samples were put in closed plastic bags and kept at 4 C until the dry matter determination were made. Sometimes to reduce the excess of moisture, the harvested forage was left on the field for two to three hours before being weighed.

The dry matter was determined using 300 g of fresh sample. In the case of corn, 3 or 4 plants were used, separating the ears from the rest of the plant and making independent determinations. Both the ears and the plant were cut in 1 cm pieces. All samples were forced air-dried at 70 C. Corn was dried for 60 h while the rest of the crops for 24 h.

Botanical analysis

A botanical analysis was done for all crops but corn. For small grains, Italian ryegrass and forage rape, the seeded crops and weeds were separated. Grasses, legumes and weeds were determined for the prairie treatments. For this kind of analysis, about 100 g of fresh forage was used.

Sample preparation for forage quality determination

Forage quality determinations, crude protein (CP), acid detergent fiber (ADF), and "in vitro" dry matter digestibility (IVDMD) were calculated for each crop and each harvest except IVDMD was not generally determined for Puenteareas samples. Three determinations of CP and ADF were done on each harvest. The dry samples which resulted from the dry matter determinations from two replications were mixed, and then ground together. So, for a particular crop, the samples from rep 1 and rep 2 were mixed, and the same procedure was followed for reps 3 and 4 and for reps 5 and 6.

For the estimation of the IVDMD, which is a more expensive procedure, only one determination per treatment was done. Normally, the replication chosen was the one whose CP and ADF values were closer to the average of the three determinations. When this procedure was not possible any of the three samples was picked. To reduce the number of analyses in corn, which was similar in several treatments, the determinations of the IVDMD were not done in all the treatments and replications but only some of the reps and treatments were randomly chosen and their results averaged. For this reason, the crop corn has the same IVDMD values for all the treatments. Also, an average of the CP and ADF values is presented and the values obtained for each treatment and replication were not used because the numbers are very similar.

Forage quality determination (ADF, CP, IVDMD)

To estimate the quality of the forages, three chemical determinations were done (ADF, CP, and IVDMD).

The ADF was calculated using 1 g of sample and following the standard method described by Goering and Van Soest (103). Crude protein was determined by a micro-Kjeldahl procedure with 0.2 g of sample using zirconium dioxide (ZrO_2) as a catalyst in the digestion stage. Nitrogen was determined in the digest by colorimetry, following a modified method from Technicon Method sheet N.36 using a Technicon AAI. The percentage N value was multiplied by 6.25 to convert it to percent crude protein. The IVDMD value was determined by a direct acidification two-stage procedure (186).

Plot size

The basic plot size was 3.2 m x 6 m, thus allowing the planting of 5 rows of corn of 80 cm wide. The plots with prairies were a little wider; they measured 4 m.

Statistical design

The field experiment had 8 treatments in a randomized block design with 6 reps. However, the statistical procedure for a crop rotation study requires data from all the crops in the rotation for every year. For this reason, the two-year rotation (corn → Italian ryegrass → forage rape) was adjusted to two different plots, one beside another, as a switch-over design, and the average of the plots was used to calculate the annual production. Something similar was used with the treatment prairies → corn, in which there were 3 different plots, each having corn at a different year. The average production of all three plots was used for the statistical analysis.

At Arzua, Mabegondo and Puebla de Brollon, the experiment started in spring 1980, where prairies and corn were seeded. However, the prairies failed to grow at Puebla because of the dry summer, and corn at Arzua because of bird damage. On the other hand, in order to be able to correctly analyze the information and to have more uniform data in all locations, it was considered that the experiment started in the fall of 1980, with the seeding of the winter crops and the prairies. That is, the data obtained from the spring of 1980 to the fall of 1980 were not used in the statistical analysis. In this way, three completed years of data, from fall 1980, to fall 1983 were available for each location. At Arzua, however, corn failed to grow in 1981 and for this reason, at this location only two years of data are considered even though the yields of winter crops and prairies for 1980-81 will be presented.

The data obtained at Puenteareas will be analyzed separately because corn was under irrigation, but not the prairies; consequently, these treatments are different from the other three locations. At Mabegondo and Arzua, from 1980, two different plots of long duration prairies were used. One was seeded during the spring of 1980, and the other in the fall of 1980. The results presented are the means of these two plots.

A basic scheme of the treatments is presented in Figure 1.

Summer Crops for Forage Production Experiments

Duration of the experiment

This research was conducted from 1980 to 1983. Four years of field data were collected in this experiment, but the chemical analyses of the forages are only for the first three years.

Field experiments

Locations Field plots were established in two locations (Mabegondo and Puebla de Brollon) with very different summer weather patterns. In Mabegondo, INIA (Spanish Institute of Agricultural Research) has its Regional Research Center, and in Puebla de Brollon a field experiment station. An outline of the weather and soil

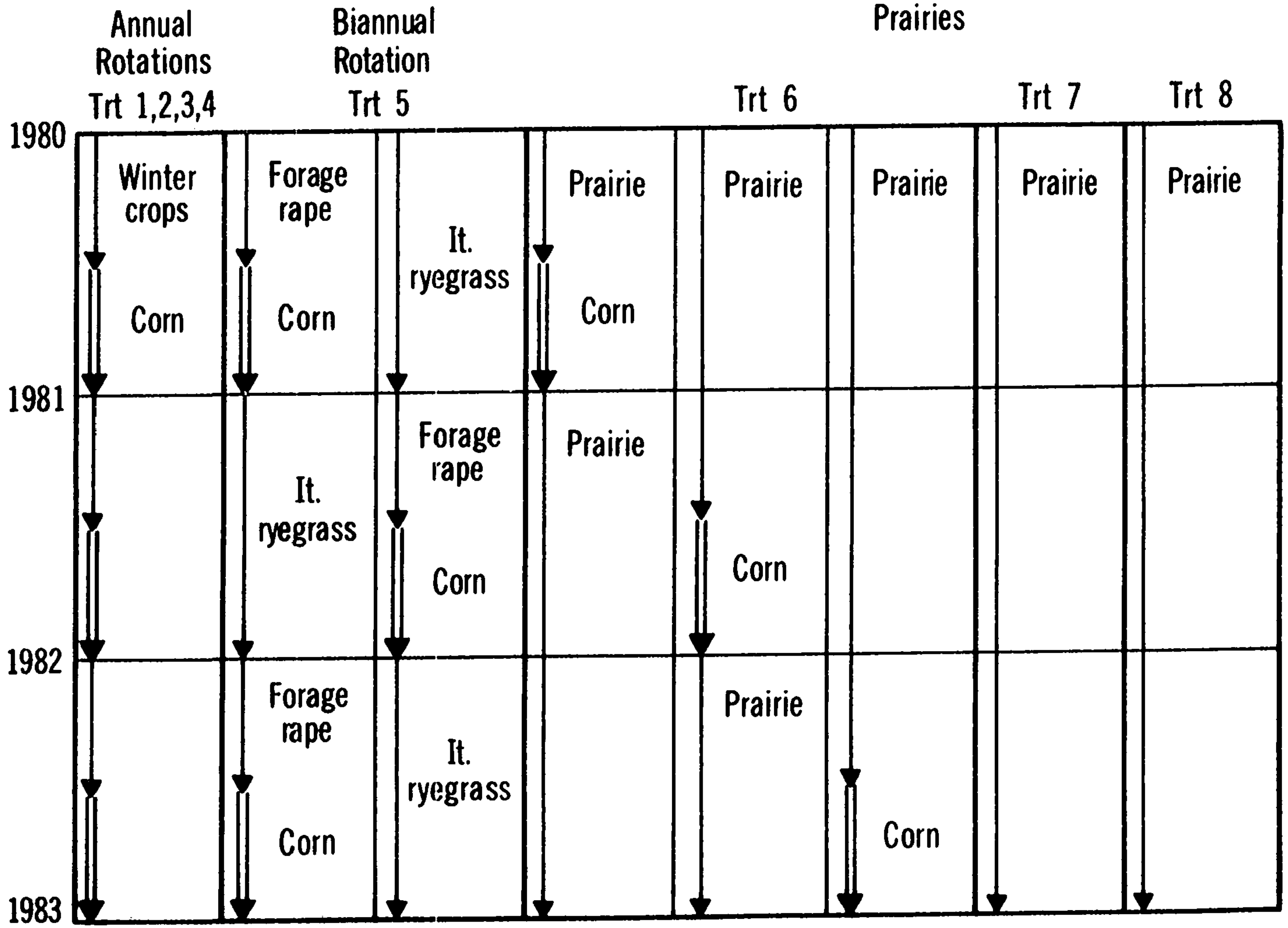

Figure 1. Basic plan of the field layout of the crop rotation experiment, from fall of 1980 to fall of 1983

characteristics of the two sites has already been presented when describing the crop rotation experiment. The plots of the two experiments were established on the same field.

Crops compared

The crops compared in this experiment were corn, sorghum x sudangrass, sudangrass, sunflower and alfalfa. This last crop is not really a summer crop, but it was included because its higher summer production potential compared with other pasture species.

Corn is the most important crop of the region and almost the only summer crop. The objective of this experiment was to understand the potential and problems of those other crops.

Crop seeding and harvesting (philosophy of the procedure)

All crops were seeded in each location according to their weather requirements, and their productions were harvested at three different dates. The harvest dates were: (a) the first week of August (1st); (b) the first week of September (2nd); and (c) whenever, according to the technical literature, each crop had its best stage for silage production (3rd). Obviously, it is very difficult to match the alfalfa cuttings with such a rigid schedule, and this crop was harvested according to its own features, regardless of the other species.

All the species except alfalfa were cut the same day in August or September for the 1st and 2nd harvests, but the date of cutting for the 3rd harvest varied according to the crop species. Corn was harvested at hard-milk dent stage, sorghum x sudangrass and sudangrass around grain forming or initial milk stage, and sunflower at the full-bloom stage for the 3rd harvest.

Soil preparation

Every year, the previous crop except alfalfa was plowed under at the end of the experiment during the fall. The next spring the land was plowed again, disked several times, and finally rotary cultivated (rotovator). Previous to the last rotary cultivation, the basal fertilization and the herbicide treatments were applied.

Agronomic aspects of the crops

Varieties, plant population, seeding rates   Corn is the most extensively grown of the crop in this region, and the varieties seeded were well-adapted to the different locations. For the earlier harvest managements (1st and 2nd), shorter than normal season varieties were used (Table 9).

For the other crops, very little research had been previously done in Galicia; for this reason, the varieties selected were standard varieties used in Spain and might not have been well-adapted to Mabegondo with a relatively cold spring (Table 10).

For corn, different plant populations for each harvesting date were used (Table 9). The population planned for the August harvest (1st) was 150,000 plants/ha with 50 cm rows. The second and third harvest managements had 80 cm rows with plant populations of 120,000 and 100,000 plants/ha, respectively. Sunflower, sudangrass and sorghum x sudangrass

Table 9. Varieties of corn used in the summer forage crops experiment

Location	Year	Harvest	Variety
Mabegondo	1980	1st	Horreo 220
		2nd	Horreo 330
		3rd	Domino 440
	1981	1st	Horreo 218
		2nd	Horreo 330
		3rd	(A619 x W182E) x EC22
	1982 and 1983	1st	Horreo 218
		2nd	Horreo 330
		3rd	Horreo 368
Puebla	1980	1st	Horreo 220
		2nd	Horreo 368
		3rd	Horreo 450
	1981	1st	Horreo 218
		2nd	Horreo 368
		3rd	Domino 440
	1982	1st	Horreo 219
		2nd	Horreo 330
		3rd	Domino 440
	1983	1st	Horreo 218
		2nd	Horreo 330
		3rd	Domino 440

Table 10. Varieties, seeding rates and plant populations used in the summer forage crops experiment

Crop	Variety	Seeding rate	Plant population
Sorghum x sudangrass	Sordan	35 kg/ha	
Sudangrass	Trudan	25 kg/ha	
Sunflower	Peredovick	25 kg/ha	200,000 to 300,000
Alfalfa	Du Puits	25 kg/ha	
Corn	(see Table 9)		100,000 to 150,000

were seeded in 50 cm rows.

A summary of the varieties, planned plant populations and seeding rates are in Tables 9 and 10. Only corn was hand thinned to get approximately the expected population. It was very difficult to do the same with sunflower because of its much higher population, and with sorghum x sudangrass because of tillering.

Fertilization The rates of fertilizer applied are presented in Table 11. The types of fertilizer used were similar to the ones in the crop rotation experiment. As in that experiment, the ratio of basic to side dressed N application varied in different years.

The fertilization for sunflower was a little different from the other summer crops. The main reason was because sunflower was considered a fast grower at the beginning of summer; by the time the N side dressing fertilization was applied to corn, sorghum x sudangrass and sorghum, the sunflower would have already made most of its growth. For this reason, even if the total amount of N was lower in 1980, 1981 and 1982 than the other three summer annual crops, the basal application was similar for all of them. In 1983, however, all crops received similar amounts of N fertilization which eliminated misunderstandings, but some N might have been wasted for sunflowers.

Alfalfa had a basic fertilization of N, P, K and Ca during the first year; for the other years, it received a top dressing fertilization of P and K by the end of winter. Prior to seeding, the seeds were inoculated.

Table 11. Fertilizer application rates (kg/ha) for the summer forage crops experiment

Crop	Year	N	P_2O_5	K_2O	CaO
Corn					
Sorghum x sudangrass					
Sudangrass					
	1980				
Basal application		80	150	100	
Side dressing		60			
Total		140			
	1981				
Basal application		100	150	100	
Side dressing		40			
Total		140			
	1982-1983				
Basal application		120	150	100	
Side dressing		20			
Total		140			
Sunflower					
	1980				
Basal application		80	150	100	
Side dressing		20			
Total		100			
	1981-1982				
Basal application		100	150	100	
Side dressing		20			
Total		120			
	1983				
Basal application		120	150	100	
Side dressing		20			
Total		140			
Alfalfa					
1st year		30	150	200	1500
Other years		--	150	200	--

Herbicides, pesticides, bird damage   The herbicides and rates used in the different crops are presented below.

Crop	Herbicide	Rate (kg/ha) active product	Method
Corn	atrazine	1.5	preplant
	alachlore	3.5	incorporated
Sorghum x sudangrass			
Sudangrass	atrazine	1.0	preplant
	propachlore	3.5	incorporated
Sunflower	E.P.T.C.	2.5	preplant incorporated

In addition to the herbicide treatments, hand weeding was done when necessary.

The most troublesome weed species were given in the crop rotation section. However, due to the type of herbicide, the proportion of the weeds that appeared in sunflower was different than in the other crops. *Cyperus sculentus*, *Echinocloa* and *Digitaria* were kept under control, and *Polygonum* became the more problematic weed. The pest problems and solutions were the same as those presented in the crop rotations section. All summer crops were affected by rootworms, but corn was the most damaged. All crops were also covered with plastic nets at Mabegondo although the birds preferred to pick the corn.

Seeding and harvesting methods, plot size

All crops except alfalfa were row seeded. A hand planter was used for corn and making a furrow, seeding and covering it in the case of sunflower, sudangrass and sorghum x sudangrass. For these three crops, the managed area consisted of three rows (50 cm between rows) and 6 m long (the length of the plot). In the case of corn, the area varied a little with the management dates. For the August harvest (1st dates), the rows were 50 cm apart and three were harvested, while for the other two harvests, two rows 80 cm apart were harvested. All crops were harvested with a head mover, and the number of plants was counted for corn and sunflower. For corn, ears and the rest of the plants were weighed separately except for the August harvests, because at that time the crop had not formed ears. Alfalfa had the same main plot size as the other crops, and the seeding and harvesting methods were similar to the ones given for the prairies in the crop rotation experiment. However, since the whole plot size was large enough, two areas for each plot were taken and the average calculated.

Dates of seeding and harvesting

The seeding dates are presented in Table 12, and the harvesting dates will be presented together with the dry matter production in the Results and Discussion section. Because of worm and bird problems, some reseeding was done when necessary to assure the planned plant population. The variations observed within a crop in the planting dates were mainly due to weather conditions. However, the observed differences between crops have a management type of explanation.

For 1980 and 1981, the planting dates were earlier than for the other years and the weather and soil temperatures were not appropriate for all crops, because of their different temperature requirements (112, 172, 182, 267, 274). For this reason, the planting was delayed for some crops, mainly sudangrass and sorghum x sudangrass, but some days later when the temperature was adequate, heavy rains impeded their planting,

Table 12. Dates of planting in the summer forage crops experiment

Location	Crop	Year			
		1980	1981	1982	1983
Mabegondo	Sunflower	April 30	April 30	May 17	May 30
	Corn	April 30	April 30	May 17	May 30
	Sorghum x S.	June 2	June 15	May 17	May 30
	Sudangrass	June 2	June 15	May 17	May 30
Puebla de Brollon	Sunflower	April 25	May 4	May 13	June 7
	Corn	May 9	May 4	May 13	June 7
	Sorghum x S.	May 29	June 16	May 13	June 7
	Sudangrass	May 29	June 16	May 13	June 7

and they might have been delayed to later than normal. However, in 1982 and 1983, all crops were seeded on the same day to avoid comparison difficulties and misunderstandings even if the sudan type crops grew slowly for some weeks, and this resulted, especially in Mabegondo, in severe weed competition.

Climatological data

The temperatures and rainfall are presented in Appendix A.

Weighting and sampling procedure

The plants were cut and weighed in the field and a sample for dry matter determination taken. For each crop and planting date, an average of 3 to 5 plants were separated, put into plastic bags and stored at 4 C while waiting for the determination of their dry matter. Sometimes to avoid excess moisture, the plants were left in the field to dry for 1 to 3 hours prior to being weighed.

Laboratory methods

All procedures and determinations followed in the crop rotation experiment were also used in this experiment. For the dry matter determinations, all crops except alfalfa were treated similarly as corn was in the rotation experiment. On the other hand, the procedure used for alfalfa was that used for prairie.

Statistical design

The field experiment was in a randomized split-plot design with 6 reps. The main plots were crops and the harvesting dates the subplots. Normally, the main plots had a 9 m x 6 m size and the 3 subplots 3 m x 6 m.

A new randomization was done every year to avoid a repetition of the same crop on the same previous year plot. With this alternation of crops, it was hoped to have a better weed control.

RESULTS AND DISCUSSION

Summer Crops for Forage Production

The results obtained at Mabegondo and those obtained at Puebla de Brollon will be presented separately. The main reason is because the two locations have a very different summer climatology (Appendix A) and also because in Mabegondo some crops failed in 1980 and 1981 and different types of comparisons need to be made.

Puebla de Brollon

The forage production obtained for corn, sunflower, sudangrass, sorghum x sudangrass and alfalfa for the different years and for the 3 dates of cutting are presented in Tables 13 to 16. An average for the four years is contained in Table 17. The quality aspects of the crops given by the percentages of CP, ADF, and IVDMD are presented in Table 18.

It is important to remember that the three dates of cutting were: 1st week of August, 1st week of September and at the silage stage, at which the date differs for each crop. For sunflower, the silage stage normally comes before the first week of August (Table 19); for this reason, the yields may be generally lower than for the other two cuttings. On the other hand, corn, sudangrass and sorghum x sudangrass were harvested for silage by mid-end of September. For alfalfa, the data presented are the total annual yield.

General comments Tables 13-16 show the dry matter production of the crops included in the experiment and have been presented to give

Table 13. Dry matter production (t/ha) of the crops at three dates of cutting in 1980 at Puebla de Brollon

Crop	August	September	Silage
Corn	5.48	9.16	8.67
Sunflower	6.73	5.01	5.42
Sudangrass	2.57	8.60	8.33
Sorghum x sudangrass	3.31	8.77	9.25
Alfalfa[a]	--	--	6.86

[a]Silage stage for alfalfa comprises the total yearly yield, weeds included.

Table 14. Dry matter production (t/ha) of the crops at three dates of cutting in 1981 at Puebla de Brollon

Crop	August	September	Silage
Corn	6.06	7.82	6.23
Sunflower	4.90	5.25	5.21
Sudangrass	0.93	4.09	5.40
Sorghum x sudangrass	0.45	3.06	5.41
Alfalfa[a]	--	--	10.58

[a]Silage stage for alfalfa comprises the total yearly yield, weeds included.

Table 15. Dry matter production (t/ha) of the crops at three dates of cutting in 1982 at Puebla de Brollon

Crop	August	September	Silage
Corn	7.49	8.84	7.41
Sunflower	7.29	8.35	6.53
Sudangrass	6.23	7.14	9.28
Sorghum x sudangrass	8.07	8.68	11.30
Alfalfa[a]	--	--	12.34

[a]Silage stage for alfalfa comprises the total yearly yield, weeds included.

Table 16. Dry matter production (t/ha) of the crops at three dates of cutting in 1983 at Puebla de Brollon

Crop	August	September	Silage
Corn	4.81	9.84	14.66
Sunflower	4.56	7.61	7.19
Sudangrass	4.10	13.72	13.53
Sorghum x sudangrass	4.88	14.52	14.47
Alfalfa[a]	--	--	12.93

[a]Silage stage for alfalfa comprises the total yearly yield, weeds included.

Table 17. Average dry matter production (t/ha) of the summer crops over the four-year period (1980-83) at Puebla de Brollon

Crop	August	September	Silage
Corn	5.96	8.92	9.24
Sunflower	5.87	6.55	6.08
Sudangrass	3.46	8.39	9.13
Sorghum x sudangrass	4.17	8.76	10.11
Alfalfa[a]	--	--	10.68

[a]Silage stage for alfalfa comprises the total yearly yield, weeds included.

Table 18. Percentage of CP, ADF, and IVDMD of the 5 crops at three stages of cutting (average 1980-83) at Puebla de Brollon

Crop	August			September			Silage		
	CP	ADF	IVDMD	CP	ADF	IVDMD	CP	ADF	IVDMD
Corn	10.35	30.39	68.26	7.29	26.09	73.98	8.23	29.02	65.75
Sunflower[a]	9.48	33.68	65.47	9.38	37.47	61.03	12.28	33.35	68.38
Sudangrass	18.43	31.57	66.74	8.89	30.27	63.97	9.07	34.58	57.06
Sorghum x sudangrass	18.06	29.13	67.82	9.26	30.04	63.56	9.32	34.58	56.00
Alfalfa[b]	--	--	--	--	--	--	20.22	32.37	66.67

[a]For sunflower, the silage cut is normally on the first cutting date.

[b]The value represents the weighted average across different cuttings and years.

an overall idea of the type of results that were obtained during the four years.

Two kinds of comparisons can be done with the data. One of them is to analyze each crop independently and discuss its production and quality through the cropping season. Another type involves the contrast of the different crops at a particular time or stage of harvest. Both kinds of examination are going to be conducted, but before, it may be interesting for the reader to have a general idea of what happened in the field during those years while the experiment was performed and which kind of factors influenced the results.

From Tables 13 to 16, it is clear that there was much variation in the yields of the crops during different years. Several factors can help to explain the irregularity, and most of them are weather related. First of all, the weather conditions, as shown in Appendix A, differed from year to year, and in 1983 a rainy spring delayed seeding time and a rainy August increased the yields of the warm season crops compared with the productions obtained in other years with the normal dry summer. Another reason that accounts for some variability is the fact that the crops have different temperature requirements for germination and growth. This is mainly true for sudangrass and sorghum x sudangrass compared with sunflower or corn. For this reason, during two of the years their seeding times were delayed relative to sunflower and corn (Table 19), but several days later when the temperatures were already appropriate, heavy rainfalls made the field impractical for seeding.

A third factor that may have had some effect was the bird and

Table 19. Dates of harvesting for the silage production treatment at Puebla de Brollon

Crop	Year 1980	1981	1982	1983	Average
Corn	Sept 17	Sept 21	Sept 17	Oct 10	Sept 24
Sunflower	July 10	July 21	July 23	August 20	July 26
Sudangrass	Sept 17	Oct 13	Sept 17	Oct 10	Sept 29
Sorghum x sudangrass	Sept 17	Oct 13	Sept 17	Oct 10	Sept 29

insect damage. In spite of the use of gas cannons and insecticide treatments, some plots were affected; and although they were reseeded, it was not always possible to get the expected plant stand (Table 20). This problem might have increased the variability among replications.

Table 20. Plant densities (plant/ha x 1000) of corn and sunflower at three dates of cutting at Puebla de Brollon

Crop	Date of cutting	Year 1980	1981	1982	1983	Average
Corn	August	143.70	152.59	145.37	169.63	152.82
	September	101.56	125.16	105.03	81.07	103.20
	Silage	69.27	105.90	84.03	96.18	88.84
Sunflower	August	150.55	355.55	324.81	292.77	280.92
	September	143.33	357.04	336.66	262.40	274.86
	Silage	148.52	347.00	279.07	262.77	259.34

The next sections will be dedicated to the discussion of the results obtained for each particular crop.

Alfalfa, because of its different characteristics compared with the annual crops, is going to be discussed separately.

Independent study of each crop

Corn The dry matter production of corn and the statistical analysis of the results are presented in Table 21. The ear/total plant ratio is given in Table 22, and the quality determinations, CP, ADF, and IVDMD in Table 23.

The dry matter yields showed a general increase with delay of harvest. The August cut was significantly different compared with the other two. The main reason why the September and silage cuts gave similar yields was the lack of moisture during August and beginning of September. This lack of water prevented the corn from developing normally, to show its genetic potential, and to respond to the higher plant density (Table 20) for the silage harvest. However, when summer rainfall was adequate as it was in 1983, the silage cut showed much better production potential, and outyielded, without question, the September harvest. The appropriate moisture in the summer of 1983 was the main factor for the significantly higher yield average in this year compared with 1980-2.

The yields obtained, except for the silage cut in 1983, when compared within Galicia or with other countries were low (8, 100, 123, 142, 208, 244, 307), and the reason is, once more, the normal lack of rainfall during the summer. Lack of moisture also might have affected the ear/total plant ratio. The harvest index as it is presented in Table 22 was about 30% and only in 1983 as high as 50%. These values are very

Table 21. Production (t/ha) and ANOVA for corn at three harvesting dates at Puebla de Brollon

Year	August	September	Silage	Average	LSD (0.05)
1980	5.48	9.16	8.67	7.77	1.87
1981	6.06	7.82	6.23	6.71	
1982	7.48	8.84	7.41	7.91	
1983	4.81	9.84	14.66	9.77	
Average	5.96	8.92	9.24	8.04	2.56 (interaction)
LSD (0.05)	1.28				

Source of variation	d.f.	Sum of squares	F value	Probability of a greater F
Year	3	87.57	4.04	0.0214
Rep (Year)	20	144.59	--	--
Cut	2	157.26	16.21	0.0001
Year*Cut	6	200.71	6.89	0.0001
Cut*Rep (Year)	40	194.07	--	--

Table 22. Yields (t/ha) and ear/total plant ratio for corn at Puebla de Brollon

Year	September			Silage		
	Ear	Total plant	Ear/total plant (x 100)	Ear	Total plant	Ear/total plant (x 100)
1980	2.74	9.16	29.91	2.04	8.67	23.53
1981	1.53	7.82	19.54	1.14	6.23	18.29
1982	2.93	8.84	33.14	2.71	7.41	36.57
1983	3.01	9.84	30.55	7.39	14.66	50.40
Average			28.28			32.19

Table 23. Percentage of dry matter in the crop at Puebla de Brollon

	Year				Average
	1980	1981	1982	1983	
August	13.60	20.08	18.24	13.77	16.42
September	26.71	30.63	31.37	19.67	27.09
Silage	28.30	30.46	38.88	49.61	36.81

low compared with the data published in other countries. For early hybrids, French data presented yields of 12.5 to 13.5 t/ha of dry matter with an ear content of about 60%, with densities up to 115,000 plants/ha (8, 9, 142). Even in Britain, near the limit for corn growth, the average yields were around 11 to 13 t/ha with 55 to 63% ear content. Also, most of the U.S. data showed ear contents above 45 to 50% (26, 61, 307).

The quality determinations for CP, ADF, and IVDMD of the corn are presented in Table 24. On the average, the August harvests had a higher protein content than either the September or silage harvests; however, their fiber content was a little lower and the IVDMD values were intermediate between the September and silage cuttings. In general, the highest quality crop was obtained with the September harvests. This might be because on this date the plants were at younger physiological maturity than the plants of the silage cuts, and even if the IVDMD and ADF of the ears were similar for both dates, the quality of the rest of the plant was much higher for September (32.12% ADF and 70.15% IVDMD) than for the silage cuts (38.34% ADF and 57.38% IVDMD).

The 82 to 84% IVDMD values for ears (Table 24), obtained at Puebla de Brollon, are similar to the percentages reported by other authors (61, 65, 244, 322). Perry and Compton (244) also presented values up to 88% for young ears. For mature leaves and stalks, they reported IVDMD values of 56 to 62% and 44 to 50%, respectively, and these are similar to the values obtained at Puebla. Cummins and Dobson (61) reported 62.9 to 72.2% IVDMD values for whole plant corn, and these are

Table 24. Percentage of CP, ADF, and IVDMD of corn at three dates of cutting at Puebla de Brollon

		August			September			Silage		
		CP	ADF	IVDMD	CP	ADF	IVDMD	CP	ADF	IVDMD
Ears	1980		Plants had		9.59	11.03	82.07	10.29	14.94	76.85
	1981		no ears		9.10	9.17	89.34	10.81	8.77	84.64
	1982		at this		8.53	10.39	83.19	10.37	10.52	81.96
	1983		stage		--	--	--	10.07	9.41	85.12
Plant without ears	1980	12.02	33.52	67.15	8.01	33.53	67.31	8.00	34.37	55.11
	1981	9.51	28.33	68.92	5.81	30.88	69.67	7.42	38.42	58.95
	1982	9.54	29.30	68.71	6.17	31.97	73.49	7.71	34.45	65.05
	1983	--	--	--	--	--	--	5.21	46.13	50.41
Average	Ear	--	--	--	9.07	10.20	84.86	10.38	10.91	82.14
	Plant	10.35	30.39	68.26	6.66	32.12	70.15	7.09	38.34	57.38
	Total crop[a]	10.35	30.39	68.26	7.29	26.09	73.98	8.23	29.02	65.75

[a]The values for total crop are average weighted values of ears and plant without ears.

also in the range of the values presented in Table 24. Several other authors published IVDMD, ADF and CP values similar to the ones obtained in this research.

Sunflower The dry matter production and the ANOVA for sunflower are presented in Table 25, and the chemical determinations for CP, ADF and IVDMD in Table 26.

The average yields for each harvest were similar, and the analysis of variance did not show significant differences. This seems to indicate that the crop made most of its growth before August, and the yield increase after this date of harvest was small. Another factor that could reduce the yields of the September harvests was the bird damage which was greatest during mid-August at the milk stage. Also, some leaf losses occurred, thus decreasing dry matter production. In 1983, the silage stage yielded more than the August harvest (Table 19) because the rainy spring delayed planting, so sunflower did not reach the silage stage until the middle of August (later than the August harvest), whereas during the other years, the silage stage was reached in mid-July. The highest dry matter yields were achieved in 1982 with 8.35 t/ha; this might have been because moisture was adequate from May until the beginning of August, which is the period when the crop generally produces most of its dry matter yield.

The reported dry matter yields for sunflower varied much depending mainly on the rainfall of the area. The mean yield of 6.17 t/ha is very close to 7 t/ha reported by Garcia (98) in other locations of Galicia. In Italy, Duranti et al. (78) presented normal yields between 6 and 8

Table 25. Production (t/ha) and ANOVA for sunflower at three harvesting dates at Puebla de Brollon

Year	Silage	August	September	Average	LSD (0.05)
1980	5.42	6.73	5.01	5.72	1.63
1981	5.21	4.90	5.25	5.12	
1982	6.53	7.29	8.35	7.39	
1983	7.19	4.56	7.61	6.45	
Average	6.08	5.87	6.55	6.17	2.57 (interaction)

Source of variation	d.f.	Sum of squares	F value	Probability of a greater F
Year	3	51.67	3.11	0.0493
Rep (Year)	20	110.61	--	--
Cut	2	5.93	2.34	0.1090
Year*Cut	6	46.95	6.18	0.0001
Cut*Rep (Year)	40	50.63	--	--

Table 26. Percentage of CP, ADF and IVDMD of sunflower at three dates of cutting at Puebla de Brollon

	Determination	Year			Average
		1980	1981	1982	
August	CP	9.45	9.42	9.60	9.48
	ADF	36.93	34.05	30.05	33.68
	IVDMD	64.89	66.94	64.58	65.47
September	CP	8.58	10.80	8.76	9.38
	ADF	45.94	34.16	32.30	37.47
	IVDMD	52.20	65.18	65.71	61.03
Silage	CP	13.39	10.90	11.44	12.28
	ADF	34.54	33.13	32.39	33.35
	IVDMD	70.84	67.58	66.73	68.38

t/ha. In Maryland, Sheaffer et al. (276), harvesting at the flowering stage, reported yields between 6 and 8 t/ha and the highest was 10.3 t/ha. In comparison with these results and others already presented in the Literature Review, the yields obtained in Puebla de Brollon can be classified as normal or somewhat below normal.

A very important factor in the production of sunflower for forage is its quality. The results presented in Table 26 show very clearly that quality decreases as the plant gets older. For the silage harvest, which normally is the first harvest, the CP content was about 12.3%, the ADF 33.35% and the IVDMD 68.38%. For the first week of August cut, CP content is already lower and also the digestibility, and by the September harvest in which the plants were already rather mature, the CP content is the lowest, the ADF values are the highest and the digestibility was the lowest.

Compared with corn, fewer forage quality studies have been published about sunflower. With the variety Peredovick, the same that was used at Puebla de Brollon, Sheaffer et al. (276) reported a great variation of ADF values depending on the year (30 to 37, 47 to 56, and 46 to 53%). The percentages at Puebla were more constant (30.05% in 1982, and 45.94% in September 1984); however, the average ADF values were between 33.35 and 37.47%.

The average IVDMD percentages at silage stage were 68.38% at Puebla, very similar to the 70.42% reported by Sheaffer et al. (276). It has to be taken into account that there is not a completely standardized method for IVDMD determinations. Their normal digestibility values were between 63 and 68%, which coincided well with the Puebla values. The CP contents of the Puebla experiment (9.38 to 12.28%) were also similar to the percentages given by Sheaffer et al. (276). These results are also in agreement with French and British publications (68, 117).

In general, it is possible to conclude that, at Puebla and using the variety Peredovick, the best relative quantity and quality was produced in this experiment at the full-bloom stage when the crop was harvested for silage, although the dry matter content, 16.26% (Table 27), might have been too low for silage making. However, the September harvest had an average of 25.34% dry matter, which would be more appropriate for a crop destined to silage.

Table 27. Percentage of dry matter of sunflower at Puebla de Brollon

	Year				Average
	1980	1981	1982	1983	
August	19.92	22.78	18.64	15.69	19.25
September	29.64	24.56	28.01	19.16	25.34
Silage	13.54	19.62	15.08	16.80	16.26

Sudangrass The productions of dry matter obtained in Puebla de Brollon are presented in Table 28 and the quality determinations in Table 29. The average August yields were 3.46 t/ha and were significantly different from the September or the silage harvests. The yields varied much from year to year. The lowest was in 1981 due to a late seeding followed by a dry summer, with only 5.40 t/ha at the

Table 28. Production (t/ha) and ANOVA for sudangrass at three harvesting dates at Puebla de Brollon

Year	August	September	Silage	Average	LSD (0.05)
1980	2.57	8.60	8.33	6.50	2.39
1981	0.93	4.09	5.40	3.47	
1982	6.23	7.14	9.28	7.55	
1983	4.10	13.72	13.53	10.45	
Average	3.46	8.39	9.13	6.99	1.94
LSD (0.05)	0.97				(interaction)

Source of Variation	d.f.	Sum of squares	F value	Probability of a greater F
Year	3	447.93	12.62	0.0001
Rep (Year)	20	236.58	--	--
Cut	2	456.64	82.17	0.0001
Year*Cut	6	138.19	8.19	0.0001
Cut*Rep (Year)	40	111.14	--	--

Table 29. Percentage of CP, ADF and IVDMD of sudangrass at three dates of cutting at Puebla de Brollon

	Determination	Year				Average
		1980	1981	1982	1983	
August	CP	19.56	24.10	10.48	--	18.43
	ADF	30.89	30.06	33.75	--	31.57
	IVDMD	68.63	65.99	65.60	--	66.74
September	CP	9.22	9.55	7.90	--	8.89
	ADF	32.11	30.91	27.79	--	30.27
	IVDMD	59.01	65.89	67.00	--	63.97
Silage	CP	10.22	12.10	7.63	6.34	9.07
	ADF	31.98	37.93	31.57	36.84	34.58
	IVDMD	58.98	54.45	60.52	54.31	57.06

silage stage compared with 13.53 t/ha in 1983, during which August had plenty of rainfall.

On the average, the yields increased with each date of harvest; however, the large increase in yield occurred between the first week of August and the first week of September, and very little production was added from the first days of September to the end of that month except in 1982 when the silage yields were almost 2 t/ha higher than the September yields. In 1981, the difference was a little more than 1 t/ha. These increases in yield might be due to rainfall during late August and the beginning of September, which caused regrowth after a period of drought (187). From the literature, it is possible to say that except for 1983, the yields obtained in Puebla are relatively low. In 1973, Pereiro et al. (243) found that this same variety under irrigated conditions produced about 14 t/ha of dry matter. Maybe with narrower rows, the yields of the August harvests would have been higher and the differences between these and September harvests would have been reduced.

The chemical determinations for CP, ADF, and IVDMD are given in Table 29. They show in general the typical trend of decreasing quality of the crop as it nears physiological maturity. The main decrease in CP contents occur from August to September, with a relatively small decrease in digestibility; however, the large decrease in digestibility occurred between the beginning of September and the silage harvests (about 29 of September). The CP content and the digestibility percentages are similar to the values published in several papers (259,

Table 30. Percentage of dry matter in the sudangrass crop at Puebla de Brollon

	1980	1981	1982	1983	Average
August	15.10	16.79	22.05	15.45	17.35
September	27.82	27.17	35.29	24.69	28.74
Silage	29.52	22.76	45.94	36.87	33.77

Table 31. Production (t/ha) and ANOVA for sudangrass at three harvesting dates including their regrowth at Puebla de Brollon

Year	August	September	Silage	Average	LSD (0.05)
1980	5.66	8.60	8.33	7.53	2.68
1981	4.59	4.09	5.40	4.69	
1982	9.07	7.81	9.57	8.82	
1983	10.03	14.78	13.53	12.78	
Average	7.34	8.83	9.21	8.46	1.79 (interaction)
LSD (0.05)	0.63				

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	609.41	13.65	0.0001
Rep (Year)	20	297.65	--	--
Cut	2	46.81	9.91	0.0003
Year*Cut	6	72.35	5.11	0.0006
Cut*Rep (Year)	40	94.46	--	--

270, 323), with some logical variations depending on location and year. The ADF contents are also in agreement with the values given by Ademosum et al. (1).

According to the data presented and taking into account the literature, it can be concluded that with the Puebla de Brollon conditions, the best quality x quantity product is obtained with beginning of September harvests.

If instead of studying the dry matter yields of the crop at a particular date, the aftermath of these harvests is included, the production is different (Table 31). The August harvest, although still significantly lower than the other two harvests, has double its production.

No forage quality determinations were done on the aftermath. However, it should be remembered that the sudan type of forages may have some dhurrin problems (325); because of that, although the regrowths were added to the initial weight at a particular harvest, these extra productions may not always be useful for animal production.

Sorghum x sudangrass The dry matter yields of the sorghum x sudangrass hybrid are presented in Table 32, and the CP, ADF and IVDMD in Table 33.

As with sudangrass, the ANOVA shows significant differences among years and among harvests. The data also show an increase in dry matter yield with delayed harvest, although the large change was between the August and September cuts. This means that most of the growth had occurred by September.

Table 32. Production (t/ha) and ANOVA for sorghum x sudangrass at three harvesting dates at Puebla de Brollon

Year	August	September	Silage	Average	LSD (0.05)
1980	3.31	8.77	9.25	7.11	2.60
1981	0.45	3.06	5.41	2.97	
1982	8.07	8.68	11.30	9.35	
1983	4.88	14.52	14.46	11.29	
Average	4.17	8.75	10.11	7.67	2.11 (interaction)
LSD (0.05)	1.06				

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	689.19	13.36	0.0001
Rep (Year)	20	280.83	--	--
Cut	2	463.88	70.41	0.0001
Year*Cut	6	146.10	7.39	0.0001
Cut*Rep (Year)	40	131.77	--	--

Table 33. Percentage of CP, ADF, and IVDMD of sorghum x sudangrass at three dates of cutting at Puebla de Brollon

	Determination	1980	1981	1982	1983	Average
August	CP	17.01	28.55	9.68	--	18.06
	ADF	29.43	27.67	30.29	--	29.13
	IVDMD	68.8]	71.54	63.09	--	67.82
September	CP	9.18	10.71	7.89	--	9.26
	ADF	32.06	30.74	27.33	--	30.04
	IVDMD	58.49	65.89	66.29	--	63.56
Silage	CP	10.02	13.10	7.95	6.21	9.32
	ADF	32.83	37.65	30.38	37.47	34.58
	IVDMD	56.74	55.37	58.31	53.59	56.00

As for the other crops, the forage yields were good in 1983 and very low in 1981 due to the different rainfall conditions. The forage quality determinations show the typical pattern described in the literature, that is, a decrease in CP contents and IVDMD and an increase in ADF as the crop advances toward physiological maturity. In this experiment, the CP decreased from 18.06 to 9.32% and the IVDMD percentage went from 67.82 to 56.00%. These results are similar to others reported in several publications (1, 50, 270).

If a harvest date had to be chosen, the first week of September may be better than to wait until the so-called silage stage. The reason is because, although the product of dry matter yield x IVDMD for the September and silage harvests is very similar (556 vs. 560 respectively), the animal production should be better with the 63.56% digestibility of the September harvests than with the 56.00% at the silage cut (1, 174). Percentage of dry matter is in Table 34.

If the regrowths were added to the initial production, the final dry matter yields increased mainly for the August harvests (Table 35). However, the comments made about the dhurrin in the sudangrass section can be applied here. With irrigated conditions, the same variety yielded in 1973 more than 16 t/ha with two harvests (243).

Table 34. Percentage of dry matter in the crop

	1980	1981	1982	1983	Average
August	15.92	16.78	24.37	16.70	18.44
September	31.18	24.93	39.56	27.57	30.81
Silage	32.12	23.92	47.94	37.24	35.30

Table 35. Production (t/ha) and ANOVA for sorghum x sudangrass at three harvesting dates including their regrowth at Puebla de Brollon

Year	August	September	Silage	Average	LSD (0.05)
1980	5.41	8.77	9.25	7.81	3.00
1981	3.65	3.06	5.41	4.04	
1982	11.04	9.34	11.55	10.64	
1983	10.95	15.79	14.46	13.73	
Average	7.76	9.24	10.17	9.05	1.90
LSD (0.05)	0.95				(interaction)

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	921.73	16.44	0.0001
Rep (Year)	20	373.83	--	--
Cut	2	71.35	13.39	0.0001
Year*Cut	6	90.74	5.67	0.0001
Cut*Rep (Year)	40	106.60	--	--

Comparisons among summer crops As it was said earlier, the second type of analysis that can be done with the summer crops is to compare their production and quality at a particular date or stage of growth. These kinds of comparisons may have a more practical application for the agronomist or farmer who has to choose among several crops available. In this experiment, the three analyses which can be done are in August, September and at the silage stage, although this stage of growth had a different date of harvest for each crop. The following sections are dedicated to the crop comparisons at these dates or stages.

<u>August harvest</u> The data obtained at the August date of cutting are presented in Table 36. The table shows that corn and

Table 36. Production (t/ha) and ANOVA of the different crops harvested on the first week of August at Puebla de Brollon

Year	Corn	Sun-flower	Sudan-grass	Sorgo x sudan.	Average	LSD (0.05)
1980	5.48	6.72	2.57	3.31	4.52	0.87
1981	6.06	4.90	0.93	0.45	3.08	
1982	7.48	7.29	6.23	8.07	7.27	
1983	4.81	4.56	4.10	4.88	4.59	
Average	5.96	5.87	3.46	4.17	4.95	1.65 (interaction)
LSD (0.05)	0.82					

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	219.29	34.57	0.0001
Rep (Year)	20	42.29	--	--
Crop	3	111.73	18.23	0.0001
Year*Crop	9	109.87	5.97	0.0001
Crop*Rep (Year)	60	122.61	--	--

sunflower outyielded sudangrass and sorghum x sudangrass, not only as an average but almost every year. The main reasons may be because of the later seeding dates for sudangrass and sorghum x sudangrass in 1980 and 1981, but also because corn and sunflower have higher growth rates earlier in the season when temperatures are not yet warm enough for the sudan type of forages.

The ANOVA for this August cutting shows significant differences among years, among crops and also the interaction of year*crop. On the other hand, if we look at Table 18 which presents the average quality for the crops, sunflower shows the lowest quality with lower protein content, higher fiber content and a little lower digestibility than the other crops. However, an individual analysis of the quality of each crop from year to year (Table 18) shows that at this date the CP, ADF and IVDMD for corn and sunflower are very constant, while sudangrass and sorghum x sudangrass values fluctuated more. This is mainly true for the CP contents which ranged from 9.68 to 28.55% for sorghum x sudan, and from 10.48 to 24.10% for sudangrass. These values are higher on the years where the seeding was delayed. However, the ADF and IVDMD percentages did not fluctuate that much. For sunflower and corn, the quality determinations changed very little from year to year, and particularly the IVDMD values were very constant.

From all these observations, it can be concluded that if forage is needed by the first week of August, corn and sunflowers should be preferred over sudangrass and sorghum x sudangrass and that corn, at this date, has a higher quality forage than sunflower. Other considerations, like cost of the seed, herbicides, machinery costs, fertilizer, etc., may make sunflowers a less costly crop and may be important in the decision process.

September harvest The results obtained for the September harvests are presented in Table 37. The statistical analysis found significant differences among crops, among years and also the year*crop interaction. The results show very clearly that on the first week of September, corn, sudangrass, and sorghum x sudangrass outyielded

Table 37. Production (t/ha) and ANOVA of the different crops harvested on the first week of September at Puebla de Brollon

Year	Corn	Sun-flower	Sudan-grass	Sorgo x sudan.	Average	LSD (0.05)
1980	9.16	5.01	8.60	8.77	7.88	1.40
1981	7.83	5.25	4.09	3.06	5.05	
1982	8.85	8.35	7.14	8.67	8.25	
1983	9.84	7.61	13.72	14.52	11.42	
Average	8.92	6.55	8.39	8.75	8.15	2.51
LSD (0.05)	1.25					(interaction)

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	488.93	29.94	0.0001
Rep (year)	20	108.87	--	--
Crop	3	85.38	6.02	0.0013
Year*Crop	9	259.71	6.11	0.0001
Crop*Rep (Year)	60	283.45	--	--

sunflower and that these crops had very similar mean yields. However, the year-to-year variability was larger with sudangrass and sorghum x sudangrass than with corn because of the weather factors already discussed in previous sections.

The average quality of the crops presented in Table 18 shows a higher CP content for sudangrass and sorghum x sudangrass (8.89 and 9.26) than for corn (7.29), but the ADF and digestibility percentages for corn (26.09 and 73.98, respectively) make this crop a much better forage than sudangrass (30.27 and 63.97) and than sorghum x sudangrass (30.04 and 63.56). These two sudan type crops had very similar quality values. Corn showed higher digestibilities than these two crops in each of the three years 1980, 1981 and 1982 where IVDMD values were available. Sunflower was lower in quantity and quality than either of the other crops.

It can be concluded that at Puebla de Brollon, with the conditions of the experiment, it seems logical to select corn as a crop for forage production at the beginning of September because although the other two crops showed similar yields, the forage quality of the corn was higher.

Silage harvest The production of the crops at the silage stage is presented in Table 38. As it was discussed earlier, the dates

Table 38. Production (t/ha) and ANOVA of the different crops harvested at silage stage at Puebla de Brollon

Year	Corn	Sun-flower	Sudan-grass	Sorgo x sudan.	Average	LSD (0.05)
1980	8.67	5.41	8.33	9.25	7.92	1.74
1981	6.24	5.21	5.40	5.41	5.56	
1982	7.41	6.53	9.28	11.30	8.63	
1983	14.66	7.19	13.53	14.46	12.46	
Average	9.24	6.09	9.13	10.11	8.64	
LSD (0.05)	1.72					

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	589.42	23.52	0.0001
Rep (Year)	20	167.09	--	--
Crop	3	222.81	8.32	0.0001
Year*Crop	9	141.10	1.76	0.0958
Crop*Rep (Year)	60	535.92	--	--

of cutting for each crop changed from year to year. For corn, sudangrass and sorghum x sudangrass, the average dates of harvesting occurred at the end of September, while for sunflower it was at the end of July, before the August harvest. For this reason, the differences for dry matter production between sunflower and the other crops were large at this stage, but the quality of sunflower was higher than for corn and the sudan type crops. The results show again the yield variability due to the weather conditions, mainly in 1981 and 1983. The average dry matter production was not significantly different between corn, sudangrass and sorghum x sudangrass. However, the quality of corn was much higher than the other two forages (65.75% digestibility vs. 56.57%), although the protein content of corn was a little lower (8.23% vs. 9 to 9.32%). According to the results, it can be concluded that if a crop was to be chosen for silage, corn seems the most appropriate, because of its high dry matter yield and higher quality than sorghum x sudangrass or sudangrass.

Alfalfa The yearly dry matter production for alfalfa and the mean quality determinations are presented in Tables 39 and 40. The yield and quality values of the crop at each particular cut are shown in Appendix B.

The results show a mean yearly yield of 10.68 t/ha if the weeds are included in the crop, and 7.93 t/ha if the weight of weeds were subtracted. The average contribution of alfalfa was 75.17%. The yield of the first year (seeding year) was lower than the next three years, but this is normal for the establishment year. Table 39 also shows

Table 39. Total annual production of alfalfa (t/ha) and number of cuttings per year at Puebla de Brollon

Year	With weeds	Free of weeds	% Alfalfa	Number of cuts
1980	6.86	5.57	81.19	3
1981	10.58	8.33	78.73	5
1982	12.34	8.24	66.77	5
1983	12.93	9.57	74.01	4
Average	10.68	7.93	75.17	4.25

Table 40. The CP, ADF and IVDMD weighed average values of alfalfa (weeds included) at Puebla de Brollon

Year	CP	ADF	IVDMD
1980	20.65	29.86	68.84
1981	23.96	32.56	68.55
1982	18.41	32.84	65.49
1983	17.87	34.24	63.82
Average	20.22	32.37	66.67

that the average content of alfalfa in the crop decreased every year except in 1983. This also is expected as the crop ages. In 1983, however, the large spring and summer rainfall made the weather conditions very favorable for alfalfa and this might have been the reason for an increase in the proportion of legume. The forage production of alfalfa varied much depending on the weather and location. Compared with the results obtained in other areas of Galicia (341), the average yields in this experiment could be considered as medium-low. In other areas of the world, yields of 22.40 t/ha have been reported under irrigated conditions and only 6.16 t/ha on dry land (189). Since no other published data are available from this area, it is difficult to make comparisons, but in general it is possible to say that the yields are medium-low. At this location, however, alfalfa production with rainfed conditions is not very high compared with other areas of the world.

The chemical determinations of CP, ADF and IVDMD show a general decrease in quality as the crop gets older. The CP contents decrease from 23.96 to 17%, the ADF increases from 29.86 to 34.24% and the digestibility decreases from 68.84 to 63.82%. In general, the data show the typical negative relationship between yield and quality (14, 160) and also a general decrease in quality with a decreasing percentage of the alfalfa in the harvest. According to the literature, the mean CP values (20.22%) obtained in Puebla de Brollon are normal and the digestibility (66.67%) is also normal for high quality forage.

Alfalfa compared with annual summer crops The forage production and the ANOVA are presented in Table 41, and the chemical quality determinations are shown in Table 18.

It is clear that at 5% level, there are no total dry matter yield differences between alfalfa and the summer crops except with sunflower. Without taking into account 1980, that was the establishment year for alfalfa, the annual comparisons show that alfalfa yielded more than the annual crops during the dry-summer years (1981-1982), while the situation was reversed during the humid-summer year (1983). The reason for this is because alfalfa makes most of its growth in the spring-beginning

Table 41. Production (5/ha) and ANOVA of the annual summer crops and alfalfa[a] at Puebla de Brollon

Year	Corn	Sun-flower	Sudan-grass	Sorghum x sudan.	Alfalfa[b]	Average	LSD (0.05)
1980	8.67	5.42	8.33	9.25	6.86	7.71	1.28
1981	6.23	5.21	5.40	5.41	10.58	6.57	
1982	7.41	6.53	9.28	11.30	12.34	9.48	
1983	14.66	7.19	13.53	14.46	12.93	12.55	
Average	9.24	6.09	9.13	10.11	10.68	9.08	3.21 (interaction)
LSD (0.05)	1.60						

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	612.31	35.91	0.0001
Rep (Year)	20	113.67	--	--
Crop	4	306.15	9.83	0.0001
Year*Crop	13	257.24	2.75	0.0035
Crop*Rep (Year)	80	622.95	--	--

[a]The summer annual crops are considered at the silage stage.

[b]The yield for alfalfa is the total annual dry matter.

of summer (Appendix B), while the annual crops have a much shorter season to grow and are very dependent on summer rainfall.

On the other hand, the quality aspects of the crops (Table 18) clearly show that alfalfa was the best crop as far as crude protein contents (20.22% vs. 8.23% for corn) and a little more digestible than corn (66.67 vs 65.75) although the ADF percentage is a little bit higher (32.37 vs. 29.02%).

From these comparisons, if only dry matter and quality factors were considered, alfalfa would be a better forage crop than corn, sunflower, sudangrass and sorghum x sudangrass. However, the ranking may change if economic or other types of factors are taken into account.

Mabegondo

The forage production for corn, sunflower, sudangrass and sorghum x sudangrass for the different years is presented in Tables 42 and 43. Sudangrass and sorghum x sudangrass yields are not available from 1980 and 1981. These two crops had at Mabegondo several problems mainly related with weather conditions and weed competition. Firstly, the sudan type crops have a higher temperature requirement for germination and growth than sunflower and corn, and the weather at Mabegondo is not very appropriate for these crops. Secondly, weeds were a severe problem. The normal herbicide recommendations for sudan type crops include the use of Propachlor and Atrazine, but these two herbicides do not work very well at Mabegondo where two of the main weeds, *Echinochloa crus-galli* and *Digitaria sanguinalis*, have similar growth pattern to sudangrass and sorghum x sudangrass and were strong competitors with the crop. Because of the weed problem, it would not be advisable to recommend these sudan type crops. In the latter years of 1982 and 1983, hand weeding was done in order to obtain production comparisons for these crops. This is the reason why only data for two years are presented. All these aspects should be kept in mind when discussing the results.

In 1983, however, some tests were done using an Alachlor antidote for sorghum or sudangrass in some small plots, and the results were

Table 42. Dry matter production (t/ha) of the crops at three dates of cutting in 1980 and 1981 in Mabegondo

Crop	August	September	Silage
	1980		
Corn	4.68	7.28	9.68
Sunflower	6.01	6.02	4.78
	1981		
Corn	6.39	11.84	11.82
Sunflower	9.71	10.44	8.09

Table 43. Dry matter production (t/ha) of the crops at three dates of cutting in 1982 and 1983 in Mabegondo

Crop	August	September	Silage
	1982		
Corn	6.95	12.05	15.51
Sunflower	5.53	8.87	4.42
Sudangrass	2.76	7.09	6.79
Sorghum x sudangrass	3.39	9.56	9.09
	1983		
Corn	2.56	9.84	14.97
Sunflower	2.45	9.59	7.84
Sudangrass	2.97	9.13	8.29
Sorghum x sudangrass	2.97	10.63	9.71

satisfactory. Although further research is needed in the area; and if the product works well, it might indicate that depending on the production, sudangrass and sorghum x sudangrass might also have to be taken into consideration.

The average dry matter yield for all the crops is presented in

Table 44 and the quality aspects CP, ADF and IVDMD in Table 45. As it was mentioned for the Puebla de Brollon experiment, the yearly

Table 44. Average dry matter production (t/ha) of the summer crops over the four-year period (1980-83) in Mabegondo

Crop	August	September	Silage
Corn	5.15	10.25	12.99
Sunflower	5.92	8.73	6.28
Sudangrass[a]	2.86	8.11	7.54
Sorghum x sudangrass[a]	3.18	10.10	9.40

[a]The data were only available for 1982 and 1983.

Table 45. Percentage of CP, ADF and IVDMD of the 4 crops at three stages of cutting (average 1980-83) in Mabegondo

Crop	August			September			Silage		
	CP	ADF	IVDMD	CP	ADF	IVDMD	CP	ADF	IVDMD
Corn	9.80	33.19	68.10	6.67	28.60	69.42	6.70	24.67	69.08
Sunflower[a]	10.06	40.36	60.48	6.56	42.07	50.78	11.35	38.79	65.11
Sudangrass[b]	15.19	39.34	59.73	7.54	38.04	57.65	6.18	38.09	56.04
Sorghum x sudangrass[b]	14.34	36.05	57.83	6.35	40.37	53.82	6.12	38.39	51.15

[a]For sunflowers, the silage harvest is normally the first cutting date.

[b]The values are based only on data from 1982 and 1983.

weather fluctuations and the bird and insect damage are the main factors that can explain the variability among years. The same kind of analyses which were done for Puebla de Brollon are also going to be conducted for Mabegondo. However, because only two years of data are available for sudangrass and sorghum x sudangrass. Corn and sunflower are going to be compared separately for four years and later a different contrast will be done for two years (1982-83) for the four crops.

Independent study of each crop

Corn The dry matter production of corn and the statistical analysis of the results are presented in Table 46, the ear/total plant

Table 46. Production (t/ha) and ANOVA for corn at three harvesting dates in Mabegondo

Year	August	September	Silage	Average	LSD (0.005)
1980	4.68	7.28	9.68	7.22	1.31
1981	6.39	11.84	11.82	10.02	
1982	6.95	12.05	15.51	11.50	
1983	2.56	9.84	14.97	9.12	
Average	5.15	10.25	12.99	9.46	1.91 (interaction)
LSD (0.05)	0.96				

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	173.41	16.18	0.0001
Rep (Year)	20	71.44	--	--
Cut	2	761.68	141.38	0.0001
Year*Cut	6	120.84	7.48	0.0001
Cut*Rep (Year)	40	107.75	--	--

ratio in Table 47 and the quality determinations of CP, ADF, and IVDMD in Table 49. The total yields showed a general increase with delaying

Table 47. Ear/total plant ratio for corn (quantities in t/ha) in Mabegondo

Year	September			Silage		
	Ear	Total plant	(Ear/total plant) x 100	Ear	Total plant	(Ear/total plant) x 100
1980	2.23	7.28	30.63	3.81	9.68	39.36
1981	3.08	11.84	26.01	4.54	11.82	38.41
1982	2.35	12.05	19.50	7.87	15.51	50.74
1983	3.03	9.84	30.79	8.58	14.97	57.31
Average			26.73			46.45

Table 48. Percentage of dry matter in the crop in Mabegondo

	Year				
	1980	1981	1982	1983	Average
August	12.98	15.86	12.97	7.37	12.29
September	23.44	26.39	22.22	21.18	23.30
Silage	30.58	27.49	37.54	35.82	32.85

Table 49. Percentage of CP, ADF and IVDMD of corn at three dates of cutting

		August			September			Silage		
		CP	ADF	IVDMD	CP	ADF	IVDMD	CP	ADF	IVDMD
Ears	1980	Plants			8.68	12.70	83.57	10.15	10.39	82.82
	1981	had no			9.42	11.01	84.41	9.19	8.27	82.16
	1982	ears at			9.42	20.10	78.50	7.53	6.62	84.71
	1983	this stage			--	--	--	7.77	4.75	85.92
Plant without ears	1980	8.67	34.02	70.74	4.50	32.86	66.59	3.98	38.66	58.17
	1981	9.08	31.17	66.96	5.39	34.53	60.83	4.19	41.83	46.36
	1982	11.66	34.38	66.62	7.48	33.17	67.24	5.11	43.91	58.67
	1983	--	--	--	--	--	--	6.35	36.88	58.72
Average	Ear	--	--	--	9.17	14.60	82.16	8.66	7.50	83.90
	Plant	9.80	33.19	68.10	5.78	33.52	64.88	4.90	40.32	55.48
	Total crop[a]	9.80	33.19	68.10	6.67	28.60	69.42	6.70	24.67	69.08

[a]The values for total crop are average weighted values of ears and plant without ears.

harvest. The ANOVA show significant differences among dates of harvest. But the main increment was produced from the August to the September harvest, as at Puebla de Brollon. When comparing both localities, it appears that higher yields were obtained at Mabegondo. The main reason is the difference in weather. The temperatures at Mabegondo are not as high as at Puebla de Brollon, but the summer rainfall is higher and the plants do not suffer as severe water stress.

The 1982 and 1983 yields for the silage cut were higher than the other two years because of the good summer rainfall. In 1983, the seeding time was delayed because of heavy spring rains, and this is the reason why August harvest yielded so little (2.56 t/ha). The average yields for the silage cut (12.99 t/ha), compared with other areas with similar climatology, can be classified as normal with a normal ear/total plant ratio (Table 47) (8, 9, 100, 142, 257). However, Table 47 shows very clearly that the ratio increased to 50 to 57% in a good year. In addition, the plant density was lower in 1983 than in 1980, 1981 and 1982 (Table 51).

The quality parameters showed the typical decrease in protein percentage as the crop matures, going from 9.80% at the August harvests to 6.70% in the September and silage cuts. However, the IVDMD values were constant for the three dates of cutting, and about 68 to 69%. Compared with Puebla de Brollon, the values for CP and IVDMD were very similar for the August harvests and a little higher for Puebla for the September harvests, maybe because different hybrids were used. For the silage harvests, the corn from Mabegondo had a lower protein content

(6.70 vs. 8.23) and higher digestibilities (69.08 vs. 65.75) than at Puebla. This might be partially explained in the sense that water stress reduced growth more than nitrate uptake and the corn at Puebla was under a greater water stress situation, making the silage yields lower than at Mabegondo.

The average crude protein for corn at Mabegondo can be considered a little lower than normal, whereas the digestibility values are in the normal range.

Sunflower Dry matter production and ANOVA for sunflower are presented in Table 52 and the chemical determinations for CP, ADF and IVDMD in Table 53.

The statistical analysis shows significant differences between the August and silage and September cuts. The yields of the first two cuts (silage cut was normally earlier than the August except in 1983) are similar, which is logical since the average cutting date for both was very similar (July 31 and August 2-3) (Table 50). The low yields of the August cut in 1983 were due to late planting dates because of heavy spring rains. On the other hand, the relatively lower yields in 1980 and 1982 may be because of lower plant densities in those years, mainly in 1980, compared with 1981 and 1983 (Table 51). Although high densities sometimes produced severe lodging where accompanied with August rainfall.

Dry matter yields of the two locations are similar for the silage and August harvests; however, the better climatic conditions at Mabegondo are shown for the September harvests which yielded an average

Table 50. Date of harvesting for the silage production treatment at Mabegondo

Crop	1980	1981	1982	1983	Average
Corn	Sept 30	Oct 6	Oct 15	Oct 17	Oct 10
Sunflower	July 22	July 20	July 28	August 23	July 31
Sudangrass	--	--	Sept 27	Oct 13	Oct 5
Sorghum x sudangrass	--	--	Sept 27	Oct 13	Oct 5

Table 51. Plant densities (plants/ha x 1000) of corn and sunflower at three dates of cutting at Mabegondo

Crop	Date of cutting	1980	1981	1982	1983	Average
Corn	August	162.59	152.59	184.44	138.52	159.53
	September	128.47	106.00	139.93	91.14	116.38
	Silage	99.48	101.04	100.52	77.60	94.66
Sunflower	August	150.55	352.78	325.92	291.30	280.14
	September	156.85	359.07	389.63	337.22	285.69
	Silage	149.63	347.41	267.22	290.18	263.61

Table 52. Production (t/ha) and ANOVA for sunflower at three harvesting dates at Mabegondo

Year	Silage	August	September	Average	LSD (0.05)
1980	4.78	6.01	6.02	5.60	2.06
1981	8.09	9.71	10.44	9.41	
1982	4.42	5.53	8.86	6.27	
1983	7.84	2.45	9.59	6.62	
Average	6.28	5.92	8.73	6.97	1.72 (interaction)
LSD (0.05)	0.86				

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	151.90	5.78	0.0052
Rep (Year)	20	175.28	--	--
Cut	2	111.69	25.52	0.0001
Year*Cut	6	142.32	10.84	0.0001
Cut*Rep (Year)	40	87.52	--	--

of 8.73 t/ha to only 6.55 at Puebla de Brollon.

The yields can be considered normal-high (chiefly for September harvests) compared with other research data (78, 98, 142, 276). The mean percentage of the dry matter contents of the crop, presented in Table 54, showed a very low content for the silage harvests, 12.66%, which may be too low for making a good silage. The September cut had a more appropriate content. However, the quality of the crop in September (50.78% IVDMD and 6.56% CP) was very low compared with the silage harvests (65.11% IVDMD and 11.35% CP). The quality of the crop showed the typical decrease with advancing maturity. As the crop matured, the CP content decreased from 11.35 to 6.56%, ADF increased

Table 53. Percentage of CP, ADF and IVDMD of sunflower at three harvesting dates at Mabegondo

	Determination	Year 1980	1981	1982	Average
August	CP	8.33	8.47	13.39	10.06
	ADF	44.10	42.44	34.54	40.36
	IVDMD	61.50	58.77	61.17	60.48
September	CP	6.07	5.99	7.62	6.56
	ADF	45.20	44.92	36.11	42.07
	IVDMD	50.76	47.77	53.82	50.78
Silage	CP	10.09	9.56	14.40	11.35
	ADF	41.77	39.90	34.71	38.79
	IVDMD	64.79	62.40	68.13	65.11

Table 54. Percentage of dry matter for sunflower at Mabegondo

	1980	1981	1982	1983	Average
Silage	12.16	13.76	10.28	14.04	12.56
August	15.06	17.67	11.64	6.30	12.66
September	29.56	24.90	24.52	17.94	24.23

from 38.79 to 42.07%, and the digestibility decreased from 65.11 to 50.78%.

Compared with Puebla de Brollon, the digestibility and the CP contents of sunflower at Mabegondo were always lower. It is important to remember that the plants at Puebla were normally under water stress situations compared with those at Mabegondo.

A recent review (336) concerning pasture species remarks that low soil moisture rarely has an adverse effect on herbage quality, and several studies have shown that plants grown under high moisture stress had a higher total sward digestibility than well-watered plants (41, 335). Even cell wall and lignin content have shown to be lower in water-stressed herbage, and also have a lower breaking strength for water-stressed compared with unstressed grass leaves. One explanation may be because, at least with perennial plants, the progress of plants to later stages of development may be retarded (37). This might be the case for sunflower also, but the present data consistently showed a better quality for the crop at Puebla than at Mabegondo. Another hypothesis could be that the plants that were under a water stress situation did not grow as tall as the plants in Mabegondo and consequently had less need for lignin and cellulose. Some data available from June 1980 (Table 55) show that at similar stages of cutting, the

Table 55. Percentage of lignin, cellulose and IVDMD in some 1980 sunflower samples

Location	Date of cutting	Lignin	Cellulose	IVDMD
Puebla	7/10/80	13.52	20.19	70.84
Puebla	8/1/80	11.94	22.78	64.89
Mabegondo	7/22/80	14.91	24.58	64.79
Mabegondo	8/2/80	15.78	25.85	61.50
Puebla	9/3/80	13.01	31.40	52.20
Mabegondo	9/2/80	15.04	29.89	50.76

lignin and cellulose contents of the plants in Mabegondo were higher than the plants in Puebla.

The chemical determinations for IVDMD, CP and ADF are in agreement with the data reported by several authors (68, 78, 117, 276). September harvests show, however, a lower than normal digestibility value, which may indicate that at that time the plants were too old for use as a forage crop. On the other hand, the dry matter percentages for the silage and August cuts may be too low for good silage making and some drying of the crop should be done before chopping the crop for ensiling.

Sudangrass The dry matter productions and the ANOVA are presented in Tables 56 and the chemical determinations in Table 57. It has been previously mentioned that only data for 1982 and 1983 are available because the crop had several weather and weed problems in 1980 and 1981 which impeded the normal development of the plants. However, in 1982 and 1983, hand weeding was done and the crop was able to grow normally.

The results showed significant differences between the August harvests and the September and silage cuts. As at Puebla de Brollon, most of the growth occurs between August and September, and very little or none from September to the so-called silage cuts (October 5). In Mabegondo, the silage cut even produced less than the September harvests (7.54 vs. 8.11), although the differences were not significantly different. This decrease may be due to some lodging, leaf drop, bird damage, etc.

The CP, ADF and IVDMD values show the typical decrease in quality with advancing maturity, the CP decreases from 15.19 to 6.18% and the

Table 56. Production (t/ha) and ANOVA for sudangrass at three harvesting dates at Mabegondo

Year	August	September	Silage	Average
1982	2.75	7.09	6.79	5.54
1983	2.97	9.13	8.29	6.79
Average	2.86	8.11	7.54	6.16
LSD (0.05)	1.27			

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	14.07	2.48	0.1467
Rep (Year)	10	56.85	--	--
Cut	2	198.96	44.39	0.0001
Year*Cut	2	5.27	1.18	0.3290
Cut*Rep (Year)	20	44.82	--	--

Table 57. Percentage of CP, ADF and IVDMD of sudangrass and sorghum x sudangrass at three dates of cutting at Mabegondo

	August			September			Silage		
	CP	ADF	IVDMD	CP	ADF	IVDMD	CP	ADF	IVDMD
				Sudangrass					
1982	15.19	39.34	59.73	7.54	38.04	57.65	5.96	39.02	52.84
1983	--	--	--	--	--	--	6.39	37.15	59.24
Average	--	--	--	--	--	--	6.18	38.09	56.04
				Sorghum x sudangrass					
1982	14.34	36.05	57.83	6.35	40.37	53.82	5.68	38.24	50.23
1983	--	--	--	--	--	--	6.56	38.53	52.08
Average	--	--	--	--	--	--	6.12	38.39	51.15

digestibility from 59.73 to 52.84% in 1982. No data are available from other years, but the trend should be approximately the same, as was shown in Puebla de Brollon (Table 29). Like sunflower, the digestibility of the crop in a dry year (1982) was superior in Puebla de Brollon compared with Mabegondo (Table 57) in each of the harvest dates. The explanation given for sunflower could also be applied here.

The yields are, in general, not very high, maybe because the location is not warm enough for this type of crop. Compared with Puebla de Brollon, the production at the silage stage was about 3 to 5 t/ha lower, for both years, although no statistical analysis was done. With the data available, it can be concluded that the best time at Mabegondo to cut sudangrass for forage production was at the beginning of September, because the crop reached its maximum production and the quality was better than at the silage stage. With a 25.22% dry matter (Table 58), it might not make a good quality silage.

Table 58. Percentage of dry matter in sudangrass and sorghum x sudangrass at Mabegondo

	August	September	Silage
		Sudangrass	
1982	13.24	26.90	26.34
1983	9.54	23.55	31.20
Average	11.39	25.22	28.77
		Sorghum x sudangrass	
1982	13.73	31.78	31.93
1983	8.62	26.37	34.52
Average	11.17	29.07	33.22

If the production of the aftermath was added to each date of cutting, the results showed (Table 59) some increase in production, mainly in the August harvest where the total yield increased from 2.86 to 5.54 t/ha. However, the data show the general pattern of decreasing yield with increasing cutting frequency (50, 132, 323).

Table 59. Production (t/ha) and ANOVA for sudangrass at three harvesting dates including their regrowth at Mabegondo

Year	August	September	Silage	Average
1982	4.98	7.66	6.79	6.47
1983	6.09	9.83	8.29	8.07
Average	5.54	8.74	7.54	7.27
LSD (0.05)	1.41			

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	22.86	3.60	0.087
Rep (Year)	10	63.52	--	--
Cut	2	62.88	11.48	0.0005
Year*Cut	2	1.71	0.31	0.7349
Cut*Rep (Year)	20	54.76	--	--

<u>Sorghum x sudangrass</u> The total dry matter yields for sorghum x sudangrass are presented in Table 60 and the quality determination in Table 57. As it was mentioned for sudangrass, only two years of data are available for sorghum x sudangrass. The crop made most of the yield between August and September where the temperatures were more adequate. There were no significant differences between the September

Table 60. Production (t/ha) and ANOVA for sorghum x sudangrass at three harvesting dates at Mabegondo

Year	August	September	Silage	Average
1982	3.39	9.56	9.09	7.35
1983	2.97	10.63	9.71	7.77
Average	3.18	10.10	9.40	7.56
LSD (0.05)	1.46			

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	1.60	0.15	0.7031
Rep (Year)	10	104.29	--	--
Cut	2	348.54	59.33	0.0001
Year*Cut	2	3.48	0.59	0.5619
Cut*Rep (Year)	20	58.74	--	--

and silage harvests (10.10 vs. 9.40 t/ha). The little lower yield of the silage harvest may be due to lodging, leaf drop, bird damage, etc.

For the two sites, the yields at Puebla de Brollon were normally higher, mainly for the silage harvests (11-14 t/ha vs. 9-9.7 t/ha). The reason may be because of more adequate temperatures for the crop at Puebla than at Mabegondo.

The quality determinations showed the general decrease in quality with advancing maturity. In 1982, the digestibility values decreased from 57.83 to 50.23%, and the protein contents from 14.34 to 5.68%. These values, as it has been reported for sunflower and sudangrass, are generally lower than the percentages obtained at Puebla de Brollon. But they are in general agreement with other data reported by different authors (1, 50, 259). However, the 50.23% IVDMD for the silage stage is somewhat lower than some of the data reported (259, 263, 270, 323).

If sudangrass is planted at Mabegondo for forage production, the best time of harvesting should be at the beginning of September, where the quality x quantity relationship is higher, and the dry matter concentration is high, about 29% (Table 58). If the production of the regrowth is considered (Table 61), the general relationship does not

Table 61. Production (t/ha) and ANOVA for sorghum x sudangrass at three harvesting dates including their regrowth at Mabegondo

Year	August	September	Silage	Average
1982	6.10	10.63	9.09	8.61
1983	5.58	11.49	9.71	8.93
Average	5.84	11.06	9.40	8.77
LSD (0.05)	1.27			

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	0.92	0.07	0.8034
Rep (Year)	10	140.52	--	--
Cut	2	170.74	38.43	0.0001
Year*Cut	2	3.30	0.74	0.4882
CUT*Rep (Year)	20	44.43	--	--

change, although the August yields increased to 5.84 t/ha instead of 3.18 t/ha. It may not always be logical to consider the September regrowth because the small quantity which was produced (2.66 t/ha) may not be safe for animal production due to dhurrin problems.

Comparisons among summer crops   As was done with the data obtained at Puebla de Brollon, the crops will be compared at a particular date or stage of growing. In Mabegondo, since no data are available for the sudan type crops for 1980 and 1981, two kinds of comparisons will be presented: first, corn and sunflower during the four years; second, all four crops during 1982 and 1983.

Corn and sunflower compared   The following sections are dedicated to the four-year comparisons between corn and sunflower at different harvest dates.

August harvests   The results are presented in Table 62. The statistical analysis did not show significant differences

Table 62. Production (t/ha) and ANOVA of corn and sunflower in the first week of August

	Corn	Sunflower	Average	LSD (0.05)
1980	4.68	6.01	5.35	1.16
1981	6.39	9.71	8.05	
1982	6.95	5.53	6.24	
1983	2.56	2.45	2.50	
Average	5.15	5.92	5.53	2.07 (interaction)

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	192.59	34.61	0.0001
Rep (Year)	20	37.09	--	--
Crop	1	7.25	2.45	0.1331
Year*Crop	3	37.15	4.19	0.0188
Crop*Rep (Year)	20	59.18	--	

among crops, although there was a significant year by crop interaction. The average dry matter yields were 5.92 t/ha for sunflower and 5.15 for corn. If the quality of the crops is compared (Table 45), corn had an average IVDMD of 68.10% and only 60.48% for sunflower, while the protein content was very similar, 9.80% for corn and 10.06% for sunflower. It is possible to conclude that if no other aspects than just production and quality are considered, corn would be preferred over sunflower for forage production at the beginning of August.

<u>September harvests</u> The data for September harvests are presented in Table 63. The ANOVA showed significant differences between the average production of corn 10.25 t/ha and the average

Table 63. Production and ANOVA of corn and sunflower on the first week of September (t/ha) at Mabegondo

	Corn	Sunflower	Average	LSD (0.05)
1980	7.28	6.02	6.65	2.01
1981	11.84	10.44	11.14	
1982	12.05	8.86	10.46	
1983	9.84	9.59	9.71	
Average	10.25	8.73	9.49	
LSD (0.05)	1.28			

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	141.28	8.44	0.0008
Rep (Year)	20	111.56	--	--
Crop	1	27.98	6.20	0.0217
Year*Crop	3	13.36	0.99	0.4188
Crop*Rep (Year)	20	90.23	--	--

production of sunflower 8.73 t/ha. In every year in these data, corn was equal or superior to sunflower production.

The quality determinations showed a much better quality for corn (69.42% digestibility and 6.67% crude protein) than for sunflower (50.78% digestibility and 5.56% crude protein). At this particular date of harvest, corn is a better crop for forage production than sunflower if only production and quality are the factors considered.

Silage stage As it has been mentioned earlier, the date at which this stage was harvested was very different for the two crops. Corn harvest was mid-October and sunflower the end of July. For this reason, the differences in dry matter production at this stage will be the maximal. The data are presented in Table 64. The mean

Table 64. Production and ANOVA of corn and sunflower at the silage stage (t/ha) at Mabegondo

	Corn	Sunflower	Average	LSD (0.05)
1980	9.68	4.78	7.23	1.60
1981	11.82	8.09	9.96	
1982	15.51	4.42	9.96	
1983	14.97	7.84	11.40	
Average	12.99	6.28	9.64	2.26
LSD (0.05)	1.13			(interaction)

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	3	109.53	10.36	0.0003
Rep (Year)	20	70.48	--	--
Crop	1	541.03	147.34	0.0001
Year*Crop	3	94.56	8.58	0.0007
Crop*Rep (Year)	20	73.44	--	--

average yields were 12.99 t/ha for corn and 6.28 t/ha for sunflower. As expected, the ANOVA showed significant differences between the crops.

The mean digestibility for corn was 69.08%, which was higher than 65.11% for sunflower. Corn had its greatest digestibility by this stage, which is the best digestibility for any of the crop planted (Table 45). However, the CP contents of sunflower (11.35%) were almost twice as large as the protein contents of corn (6.70%). If the sunflower crop is to be used as silage at this stage, it should be allowed to dry because the dry matter content (about 12%) is too low for silage making (Table 54).

Corn showed a clear advantage over sunflower as a crop for silage. However, if a short season crop is needed, the use of sunflower should be considered.

<u>All crops compared</u> Corn, sunflower, and the sudan type crops will be compared on the basis of two years of data (1982-1983), because no yields for sudangrass and sorghum x sudangrass were available for 1980 and 1981. It was previously mentioned that these two crops had several practical field problems.

<u>August harvest</u> The dry matter production and the ANOVA are presented in Table 65. The ANOVA showed a significant difference among crops, and the LSD indicated that corn (4.75 t/ha) was superior to sudangrass (2.86 t/ha) and sorghum x sudangrass (3.18 t/ha) and that sunflower (3.99 t/ha) yielded more than sudangrass. These relations are normal because during June and July, the temperature might not

Table 65. Production (t/ha) and ANOVA of the four crops on the first week of August (1982 and 1983) at Mabegondo

	Corn	Sun-flower	Sudan-grass	Sorghum x sudan.	Average	LSD (0.05)
1982	6.95	5.53	2.76	3.39	4.65	0.82
1983	2.56	2.45	2.97	2.97	2.74	
Average	4.75	3.99	2.86	3.18	3.69	1.37
LSD (0.05)	0.97					(interaction)

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	44.18	27.07	0.0004
Rep (Year)	10	16.32	--	--
Crop	3	26.08	6.43	0.0017
Year*Crop	3	42.74	10.54	0.0001
Crop*Rep (Year)	30	40.56	--	--

be warm enough for good sudangrass or sorghum growth, while there are more appropriate for corn and sunflower.

The quality determinations for sudangrass and sorghum x sudangrass are available only for 1982 and part of 1983. Sudangrass and sorghum x sudangrass had about 15% CP, while corn reached about 10%; however, the digestibility of corn was more than 10% higher (Table 45). And, at least, at this date of cutting, sunflower was the second in digestibility but very close to sudangrass and had a crude protein content similar to corn. These relationships also held for 1982, the only year where CP, ADF and IVDMD values are available for the sudan type crops.

Taking into account only dry matter production and quality at Mabegondo for the August harvest, corn would be the most appropriate crop for forage production because it yielded better than the other crops and had a higher digestibility. Although the crude protein contents was lower for corn, the product dry matter yield x CP was higher than for sudangrass or for sorghum x sudangrass. If other economic, harvesting procedures etc. aspects are considered, then crops other than corn might be chosen.

A visual comparison of the 1982 and 1983 dry matter yields at Mabegondo and Puebla showed higher yields for Puebla de Brollon; this might be because spring and summer temperatures are normally high in Puebla.

September harvest The dry matter production and the ANOVA are presented in Table 66. The analysis of variance showed

Table 66. Production (t/ha) and ANOVA of the four crops in the first week of September (1982 and 1983) at Mabegondo

	Corn	Sun-flower	Sudan-grass	Sorghum x sudan.	Average
1982	12.05	8.87	7.09	9.56	9.39
1983	9.84	9.59	9.13	10.63	9.80
Average	10.95	9.23	8.11	10.10	9.59
LSD (0.05)	1.96				

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Year	1	1.97	0.30	0.5961
Rep (Year)	10	65.69	--	--
Crop	3	53.12	4.28	0.0126
Year*Crop	3	30.07	2.42	0.0855
Crop*Rep (Year)	30	124.24	--	--

significant differences among crops and the LSD indicates that corn (10.95 g/ha) and sorghum x sudangrass (10.10 t/ha) were superior to sudangrass (8.11 t/ha). Sunflower had an intermediate position. However, looking at the mean quality values in the September harvest (Table 45), the differences for digestibility between corn (69.42%) and the other crops were even higher than for the August cuttings. Sudangrass was 57.65% digestible and sorghum x sudangrass 53.62%, while the protein content was very similar for these three crops, abcut 6.3 to 7.54%. On the other hand, sunflower had the lowest quality and the lowest digestibility although similar in protein content.

Comparing the four plants, corn should normally be recommended for forage production at the beginning of September.

The yields at Mabegondo and Puebla de Brollon for 1982-1983 were similar. In 1982, corn yields were better at Mabegondo, normally because of less water stress, and in 1983 sudangrass and sorghum x sudangrass crops were much better at Puebla. The most reasonable factor was because higher temperatures at Pueblo de Brollon than at Mabegondo created a better growth condition for these Sudan type crops.

<u>Silage harvest</u> The dry matter production and ANOVA are presented in Table 67. The results clearly showed a great advantage for corn (15.24 t/ha) compared with the other crops (sunflower 6.13 t/ha, sudangrass 7.54 t/ha and sorghum x sudangrass 9.40 t/ha). The digestibility of corn was much higher (69.08%) than the sudan-type crops (51.15-56.04%). It is clear that at Mabegondo, if a large quantity of forage for silage is needed, corn was the most appropriate crop to

Table 67. Production (t/ha) and ANOVA of the four crops at the silage stage at Mabegondo

	Corn	Sun-flower	Sudan-grass	Sorghum x sudan.	Average
1981	15.51	4.42	6.79	9.09	8.95
1983	14.97	7.84	8.29	9.71	10.20
Average	15.24	6.13	7.54	9.40	9.57
LSD (0.05)	2.05				

Source of variation	d.f.	Sum of squares	F-values	Probability of a greater F
Year	1	18.81	1.72	0.2188
Rep (Year)	10	109.25	--	--
Crop	3	577.96	31.80	0.0001
Year*Crop	3	25.14	1.38	0.2669
Crop*Rep (Year)	30	181.75	--	--

seed.

Comparing the two locations, Tables 38 and 67 show that on a normal year (1982), corn production at Mabegondo was higher than at Puebla de Brollon with rainfed conditions, mainly because of the water stress at Puebla, but yields of corn were similar during the rainy summer. However, the production of the Sudan-type crops were always superior at Puebla de Brollon, where higher summer temperatures are advantageous for these crops.

General discussion

Puebla de Brollon In general, the average yields of the crops, when compared with other areas of the world, are not very high, and the main reason for this is because of the normal summer drought. However, with a rainy summer, as in 1983, the yields of corn, sudangrass and sorghum x sudangrass almost doubled. This may give some indication of the production potential of the area where summer irrigation is possible.

Analyzing each crop individually, the average yields and quality of the crops indicated that with the conditions of this area, corn should be harvested at the beginning of September and the same was true for sudangrass and for sorghum x sudangrass. The result shows that further growth is very restricted in normal years. Sunflower, however, made most of its growth before August and should be harvested before that date.

The comparison of the annual crops at three different dates and stages clearly showed an overall superiority of corn to the other crops. In August, corn competes favorably with sunflower because of its higher quality. On the other dates, in September and at the silage stage, the yields of corn, sudangrass and sorghum x sudangrass are similar, but again the quality of the corn was much higher than the other two crops.

It can be concluded that if only dry matter production and quality aspects of the annual summer crops are considered, corn is the most appropriate crop for summer forage production in Puebla de Brollon. On the other hand, if the summer crops were compared with the yearly production of alfalfa, this legume showed to be a better forage producer than any of the other four crops. It yields as much as any of them, and its quality, mainly its protein content, is much higher.

Mabegondo and Mabegondo vs. Puebla de Brollon   Mabegondo compared with Puebla de Brollon has somewhat more rain and cooler temperatures during the summer. This is the main factor that can explain most of the variation observed between the two locations.

The yields of corn in September and at the silage stage are always higher at Mabegondo than at Puebla, except during the rainy 1983, mainly because the plants were not under as much water stress at Mabegondo.

For sunflower, the average yields were very similar for the August and the silage harvests; however, the production of the September cut at Mabegondo was higher than at Puebla, indicating that the plants did not have the same water deficit and they were able to grow during August.

Sudangrass and sorghum x sudangrass are crops that have relatively high temperature requirements and do better at hot dry conditions than do corn or sunflower. For this reason, these sudan type crops yielded much better at Puebla than at Mabegondo. At this location, the plants did not seem very well-adapted to the mild weather conditions and had several practical agricultural problems that have to be solved before making any kind of recommendation.

At Mabegondo, the best harvesting time for corn was at the silage stage, normally at the beginning of October, because of the higher yield and similar quality at the September harvests. Sunflower at Mabegondo made most of its growth before August. For this reason and because of quality aspects, it should be harvested by this time. However, because of the low dry matter contents of the crop by these dates, it would be better to use the sunflower as a green fodder than as a silage crop. Sudangrass and sorghum x sudangrass, if they can be grown without problems, made most of the growth before September and should be harvested at this time for a better quality forage.

In general, it is clear that at Mabegondo corn was the most appropriate crop for summer forage production. At the beginning of August, corn and sunflower have similar yields but corn produces a better quality forage. On the first week of September or at the silage stage, corn yields similar or more than sudangrass, sorghum x sudangrass or sunflower; however, the forage quality of corn is much better than that of the other crops.

As an overall conclusion about the summer crops compared in this experiment, if only forage quality and quantity are considered, corn seems to be the most appropriate crop for the production of forage at Puebla de Brollon and Mabegondo. The other crops could be adequate at certain dates, if other factors like seeding and harvesting time, economics, management and destination of the crop etc. are considered.

Crop Rotations for the Production of Forages

Initially, the data obtained in the four locations will be presented separately. A comparison among localities will be discussed in a later section.

Mabegondo

The final total dry matter yields for each rotation, the CP, IVDMD values and the ANOVA table for the rotations are presented in Table 72. A summary of the dry matter yields for each cropping season is given in Table 73. Finally, a detailed exposition of the yields and quality determinations of the crops throughout the duration of the experiment is shown in Tables 68 and 69.

First, the yield and quality of each crop will be discussed, and after this, the next section will be dedicated to the analysis and comparisons of the crop rotations themselves.

Analysis of crop yields and quality

Corn The dry matter yields, ear/total plant ratio, CP, ADF and IVDMD values are given in Table 68. The average yields of corn varied very little with years and the lower production during 1981 (13.00 t/ha) compared with 1982 and 1983 (14.33 and 14.65 t/ha, respectively) should be mainly due to the lack of rainfall (.9 mm) during August of 1981. The average dry matter yields compared with other Galician results and with other areas of somewhat similar climates can be classified as normal to slightly better than normal (8, 9, 100, 142, 244, 307). The ear/total plant ratio values went from 50.58% in 1981 to 61.23% in 1983. These values are normal, although the 50.58% in 1981 was a little low. There might be several reasons; the first is that the dry summer during 1981 did not allow the crop to reach its full production potential. The highest value in 1983 (61.23%) could be due in part to the excellent summer rainfall and also to the lower plant density (72,000

Table 68. Average dry matter yield (t/ha) and percentages of CP, ADF and IVDMD of corn on different rotations and years at Mabegondo

Year	Rotation	D.M.	(Ear/total plant) x 100	CP	ADF	IVDMD	Density (plant/ ha)
1981	Corn	10.65	47.69	6.66	25.83	67.50	
	C→rye	12.57	52.18	6.58	25.55	68.23	
	C→oats + v.	13.66	51.46	7.35	25.44		
	C→It. ryegrass	12.35	47.37	6.02	27.67		
	C→It. R→Rape	15.14	54.09	7.20	25.21	70.63	
	Pastures→C	13.64	50.73	7.06	25.40		
Average		13.00	50.58	6.81	25.85	68.78	93,135
1982	Corn	14.51	52.10	5.47	23.66		
	C→rye	14.97	56.91	5.43	22.72	71.77	
	C→oats + v.	14.80	57.36	6.27	21.33		
	C→It. ryegrass	12.29	54.08	5.50	22.98		
	C→It. R→Rape	14.94	58.36	6.55	20.96	72.17	
	Pasture→C	14.47	56.80	6.67	20.93		
Average		14.33	55.93	5.98	20.09	71.97	92,055
1983	Corn	15.22	57.68	6.56	21.50	70.76	
	C→rye	13.93	59.00	6.72	20.29	70.69	
	C→oats + v.	14.98	61.28	6.57	19.69	72.84	
	C→It. ryegrass	13.87	64.33	6.36	18.22	77.38	
	C→It. R→Rape	14.98	62.68	6.66	19.23	74.64	
	Pastures→C	14.96	62.43	6.50	19.49	74.32	
Average		14.65	61.23	6.56	19.73	73.44	72,027
Average 1981-83							
	Corn	13.46	52.49				
	C→rye	13.82	56.03				
	C→oats + v.	14.48	56.70				
	C→It. ryegrass	12.83	55.26				
	C→It. R→Rape	15.02	58.37				
	Pastures→C	14.36	56.65				
Average		14.00	55.92	6.45	21.89	71.39	85,940
ANOVA		n.s.					

plants/ha, compared with about 92,000 plants/ha). The ear/total plant values may have had a direct effect on the total crop digestibility which increased proportionally to the ear/total plant increases.

The digestibilities obtained in the experiment are in the range of the values reported by several authors (58, 61, 65, 244, 322) and the ADF values showed the typical decrease with increasing digestibilities. The crude protein contents, however, were a little lower than several values reported (9, 97, 244, 307).

The average results of corn on each rotation are presented in Table 68. The yields ranged from 12.83 t/ha in the rotation of corn → It. ryegrass to 14.48 and 15.02 t/ha for the rotation of corn → oats and corn → It. ryegrass → rape. However, the ANOVA did not show any significant differences. The results indicated that It. ryegrass might not be as good of a previous crop for corn because the trend of lower yields is similar every year. However, most of the variation could be due to experimental error.

<u>Rye</u> The average dry matter yields of rye were 4.46 t/ha (Table 69), although there was some yearly variation due to climatic and agronomic factors. The lower quality of the crop in 1983, compared with 1981 and 1982, was mainly due to delayed harvesting because of the rainy spring and compared with the other years, the crop was at a later stage of maturity. The forage yield of rye depends much on the stage of cutting. In this experiment, the crop was always harvested at the vegetative stage and for this reason the yields were not very high, but they can be considered normal when compared with other results reported

Table 69. Average dry matter yields (t/ha) and percentages of CP, ADF and IVDMD of the crops at the different cropping seasons at Mabegondo

Crop	Cropping season	DM	CP	ADF	IVDMD
Rye	1980-81	3.79	22.22	29.78	72.84
	1981-82	4.87	16.13	26.31	74.87
	1982-83	4.71	9.68	31.28	66.80
	Average	4.46	16.01	29.12	71.50
Oats+vetch	1980-81	4.07	23.13	26.54	73.87
	1981-82	6.32	21.30	28.57	76.84
	1982-83	5.27	13.84	35.05	63.59
	Average	5.22	19.42	30.05	71.43
It. ryegrass (6 months)	1980-81	4.18	21.03	24.75	77.47
	1981-82	4.47	10.20	25.24	81.65
	1982-83	4.22	9.22	25.24	78.30
	Average	4.29	13.48	25.07	79.03
It. ryegrass (12 month)	1980-81	11.02	18.49	29.45	73.32
	1981-82	15.88	14.29	32.02	67.00
	1982-83	11.62	10.93	25.24	62.82
	Average	12.84	14.57	28.90	67.71
Rape	1980-81	4.77	17.33	24.03	84.35
	1981-82	7.26	12.33	25.38	83.76
	1982-83	3.77	10.54	26.74	76.59
	Average	5.26	13.40	25.38	81.55
Prairies (short duration)					
Rot. Prairies → corn					
a. Whole year production (mean of two plots)	1980-81	12.41	21.04	30.73	64.47
	1981-82	15.60	16.49	31.46	63.61
	1982-83	15.27	15.19	35.20	63.92
	Average	14.42	17.57	32.46	64.00
b. From fall until corn seeding of the plot that will carry corn	1980-81	3.78	25.99	26.31	72.35
	1981-82	5.93	21.58	31.14	68.03
	1982-83	5.19	17.45	33.13	63.16
	Average	4.96	21.67	30.19	67.84
Prairies (short)	1980-81	12.93	16.96	29.61	68.48
	1981-82	15.73	16.67	31.12	65.41
	1982-83	12.62	15.16	35.37	63.91
	Average	13.76	16.26	32.03	65.93

Table 69. (Continued)

Crop	Cropping season	DM	CP	ADF	IVDMD
Prairies (long)	1980-81	9.96	18.07	28.62	73.29
	1981-82	13.17	19.12	28.96	71.12
	1982-83	13.33	16.74	31.66	67.73
	Average	12.15	17.97	29.74	70.71

by several authors (53, 143, 155, 200, 337).

The CP, ADF and IVDMD values for 1980-81 show that for these years the crop was harvested at the stage which produced high quality forage. The CP ranged from 16.13 to 22.22% and the digestibility values between 72 and 75%. However, in 1983 the protein contents and the digestibility values were much lower, showing the effect of delayed harvesting (9.68 and 66.80%, respectively).

The quality parameters can change much depending on the variety, climate, fertility conditions, etc.; however, the values obtained in this experiment in general agree with the results reported by several authors. Other data from Galicia show a 14 to 17% CP at early heading (175). In Ireland, Keane (155) obtained mean CP contents between 12.5% and 22.3% and IVDMD percentages between 63.8 and 84.3%, depending on the date of cutting. In Denmark, Mølle (200) reported protein contents between 11.35 and 15.1% and IVOMD between 67 and 75%. Corral et al. (53) presented IVOMD of more than 70% at vegetative stage and only of about 50% at maturity and the N contents dropped from about 3% to less than 1%. Helsel (121) reported similar IVDMD percentages but somewhat lower protein contents. In general, it can be concluded that rye produced a good quality forage.

<u>Oats and vetch</u> The average dry matter yields were 5.22 t/ha, the CP was 19.42%, the ADF was 30.05% and the IVDMD was 71.43% (Table 69). As it happens with rye and other grasses, the yield depends much on agronomic factors, and the quality is mainly associated with the stage of harvesting. The DM yields in 1982 (6.32 t/ha) were higher than in 1981 (4.07 t/ha) and 1983 (5.27 t/ha), and the reason could be the mild winter between 1981 and 1982. During that winter, the oats made an excellent growth before December, and during January of 1982 the crop lodged because of the rainfall. To avoid spoiling of the forage, the crop was harvested during January and its regrowth was harvested again before seeding corn in the spring. The same growth pattern occurred during the winter of 1980-81. For both years, the regrowth of the oats by mid-February was not very much, but since the vetch had less competition, it grew very well and in some plots it was almost the only crop of the association. In 1982, however, the seeding time was delayed because of the rainfall, and in that winter the mixture did not grow as much as in the other years and no lodging occurred. On the other hand, in that year a rainy spring delayed harvesting and the crop was cut at a later physiological stage than in the other two years. All these factors can explain the high CP and digestibility values in 1981 and 1982 (73.87 and 76.84% digestibility, respectively) compared with 1983 (63.59% digestibility). However, for 1983 with a delayed harvest, the CP contents (13.84%) were high compared

with rye (9.68%), and the main reason could be the effect of vetch in the mixture.

The dry matter yields obtained in this experiment generally agree with other data reported in Galicia (98, 175). Other papers published in Australia about A. strigosa and mixtures of legumes + A. strigosa presented yields ranging from 2.03 to 7.53 t/ha, with an average protein content of 17.8% (23, 156). Compared with results reported with other types of Avena species, the results obtained at Mabegondo may not appear to be high, but the crop in this experiment was always harvested at the vegetative stage and this had an effect on the dry matter yield.

The protein and digestibility percentages presented by different authors differ much and depend on the stage of harvesting. In Galicia, Lloveras (175) in other experiments obtained similar values. In New Zealand, digestibilities of 90% at the vegetative stages and of 55 to 65% at the more mature stage have been published (191). In North Dakota (82), two spring high-protein varieties gave 15.6% CP at 50% heading, while at maturity the contents were only 10.8%. Demarquilly (67) reported IVOMD for oats of 57% at the dough stage and about 65% at flowering, while the crude protein values were 6.3 and 10.1%, respectively. In Minnesota, Marten (184) reported a 77.6% IVDMD for spring oats at the boot stage and 56.8% at the dough stage, while the protein concentrations were 20.5 and 11.5%, respectively.

The reports published for hairy vetch in central Spain show a dry matter yield of 2.66 at the vegetative stage and 5.99 t/ha at the end of flowering. At the same time, the CP content was 31.40 and 20.85%, respectively (308). Several U.S. studies show that although the dry matter yields of the oats-vetch mixture did not increase compared with the oats alone, the inclusion of winter vetch notably increased the yield of protein per ha (2, 268). The results obtained in Mabegondo seem to confirm this point, because in 1981 and 1982 where the proportion of vetch was very important, the CP values were much higher than in 1983. Also, the mean CP contents for oats + vetch were much higher than any of the winter crops.

In general, the information obtained at Mabegondo is in agreement with the data published in several papers and reflects the beneficial effect of the vetch in the mixture of oats and vetch.

Italian ryegrass The results obtained at Mabegondo show an average dry matter production of 4.29 t/ha for the ryegrass seeded in the fall and harvested before corn (6 months) and 12.84 t/ha for the crop seeded in the fall after corn and plowed under the next fall before the rape (12 months) (Table 69). The total yields of ryegrass can change greatly depending on the amount of N fertilizer, number of cuttings, stage of harvest etc. and for this reason the results reported by different authors differ. For Italian ryegrass (6 months), the yields at Mabegondo are very similar to the ones presented by Raphalen in France (256). For ryegrass seeded in the fall which stays in the field for a year, the results are similar to others reported in Galicia (250, 340), although lower than yields presented in other countries with 300 kg/N a year. There is also some variation among years. In

1982, the production (15.88 t/ha) was clearly superior to 1981 and 1983 (about 11 t/ha). The reason could be the mild winter of 1981-82 and the excellent spring conditions in 1982.

The quality of the crop greatly decreases from the vegetative to the reproductive stage. Some French data (144) showed a 75-80% IVOMD at the leaf stage and 65-70% for the heading stage. Lower values (62-65%) were reported for the heading stage of the aftermath. The crude protein contents varied in England (287) from 19% with frequent cuttings to 8.5% and 6.5% at 10 days after ear emergence. In the same country, Aldrich and Dent (3) showed about 80% dry matter digestibility in early season and about 60-65% after ear emergence. In some results reported in Louisiana (124), the IVDMD decreased from 78.5% in February to 56.8% for the fifth cutting in May.

The crude protein content of the Italian ryegrass (6 months) varied greatly in this experiment from year to year (from 21.03 to 9.22%). The reason could be mainly because in 1981, the ryegrass was harvested by March 26, much sooner than in 1982 (April 14) or in 1983 (April 24), and also because in 1981 the grass had been previously harvested during mid-February due to lodging. However, the digestibility of the crop did not change very much for the different years (77.47 to 81.65%).

The digestibility of the Italian ryegrass (12 months) was as expected lower than for Italian ryegrass (6 months) (67.71 vs. 79.03%, respectively). This is normal for several reasons: First, the crop which only lasts for 6 months is usually harvested before heading, while the crop that stays 12 months normally heads by mid-end of spring and also the regrowths head before cutting. On the average, the 6 month crop is at a much younger physiological stage when the last cut is made during the spring. Second, a number of reports (124, 144, 287) show that the quality of the aftermath is usually lower than the first cut. In this experiment, the ryegrass for 12 months was normally cut 4 to 5 times, while the ryegrass 6 month was generally harvested only one time.

The ADF percentages were also higher for Italian ryegrass for 12 months showing poorer quality compared with ryegrass for 6 months (28.90 vs. 25.07%). The average crude protein values of the two ryegrass crops were similar (13.48 and 14.57%). The relative values varied depending on years, and the variation may be due to different cutting schedules for the two crops and to the timing of the N applications.

Comparison of the winter crops after corn (rye, oats with vetch and Italian ryegrass, 6 months) The analysis of variance presented in Table 70 did not show significant differences for the dry matter production of the crops, although on the average the oats + vetch mixture gave higher yields (5.22 t/ha) compared with rye (4.46 t/ha) or Italian ryegrass (4.29 t/ha).

If the crops were to be used for green fodder and with labor available, oats and vetch would be the recommended crop after corn. However, if the crop was to be used for silage, the oat-vetch mixture at Mabegondo does not appear to be promising, at least with the varieties and

Table 70. Analysis of variance of the comparison of the dry matter production of the winter crops (rye, oats + vetch, Italian ryegrass) after corn at Mabegondo (1980-83)

Crop	Production (t/ha)
Rye	4.46
Oats + vetch	5.22
Italian ryegrass (6 month)	4.29

Crop season	Production (t/ha)
1980-81	4.01
1981-82	5.22
1982-83	4.73
LSD (0.05)	0.54

Source of variation	d.f.	Sum of squares	F-values	Probability of a greater F
Rep	5	4.91	0.31	0.8954
Crop	2	8.84	1.40	0.2910
Rep*Crop	10	31.54	--	--
Crop season	2	13.34	10.58	0.0003
Crop season*Crop	4	6.25	2.48	0.0651
Error	30	18.91	--	--

management used. The reason is because in two of the three years, the crop lodged during the winter, whereas Italian ryegrass only lodged one year and the rye did not lodge.

Of the three crops, oats and vetch gave the highest protein content and the highest dry matter x digestibility production. However, for maximum ruminant dry matter intake, Italian ryegrass seems more appropriate because of its higher digestibility.

Rye, on the other hand, had a similar quality to that of oats, although its production and CP content was lower. Every crop shows some quality variation depending on the year, although in general Italian ryegrass was more digestible and oats + vetch gave higher protein contents.

Forage rape The average dry matter yields (5.26 t/ha) are as high as the oats + vetch mixture; however, forage rape showed a greater year-to-year variation (Table 69). The reason might be the more delicate management needs for this crop. In 1982, the seeding time was delayed because of the rainy fall, and in 1983 yields were more affected than the other winter crops (rye, oats and Italian ryegrass). Also, for the variety used in this experiment and for the conditions of Mabegondo, the crop did not appear to be very winter hardy and also it was more easily attacked by insects than were the other winter crops.

The digestibility of the forage rape, on the other hand, was better than that of any other crop and also rather constant, with an average of 81.55%. The crude protein content (13.40%) was lower than rye and oats + vetch but similar to Italian ryegrass. In general, it is possible to consider forage rape as a suitable crop, although it needs more careful management and pest control.

The yields obtained in Mabegondo are a little higher than others reported in England where they use the plant as a catch-crop after barley or where it is pastured before December (99, 277). However, other data from France, Australia and also England present dry matter yields between 3 and 7 t/ha (116, 145, 293). The production can vary depending on the stage of cutting. Most of the papers about rape show high digestibilities from 70 to 85% (15, 77, 99, 152), with a little higher protein content than that obtained at Mabegondo.

Short- and long-term prairies The dry matter yields of both types of prairies, which also includes the prairies of the rotation prairies → corn, are presented in Table 69. The average of these three years of data shows that the short-term prairies, called F_2, gave higher yields (13.76 t/ha) than the long-term prairies, called F_6 (12.15 t/ha), although the statistical analysis did not show significant differences (Table 72). However, the quality parameters of both mixtures show that the long-term perennial ryegrass + white clover produces a better quality forage (17.97% CP and 70.71% IVDMD) than the F_2 (16.26% CP and 65.93% IVDMD) composed of Italian ryegrass, orchardgrass, ladino and red clover.

The reasons for these quantity and quality differences in production are several. The F_2 mixture normally has the highest yield for the first year of production, due to the Italian ryegrass and red clover. Then after this year, most of the ryegrass disappears and orchardgrass becomes the dominant species of the mixture. This substitution generally has some detrimental effect, mainly on quality, because orchardgrass is considered to be a lower quality grass than the ryegrasses (258). The results obtained at Mabegondo show these points. The dry matter yields for all three years were very similar (about 12.43 t/ha), but in 1982, as it was previously reported for the winter crops, the more ideal growing conditions increased the yields (15.73 t/ha).

However, the average quality of the pasture decreased with age. The digestibility value for the first year was 68.48%, 65.41% for the second and 63.91% for the third, and the crude protein contents went from 16.96 to 15.16%. The long-term prairies (F_6) are expected to yield less in the seeding year and, with good management, to stabilize the yields for the next several years. The data presented in Table 69 show this situation. In 1981, the yields were lower (9.96 t/ha) than in the other two years in which the yields were similar (about 13 t/ha). The quality of the crop, however, decreased a little with age, going from a 73.29% digestibility in 1981 to 67.73% in 1983. However, the crude protein contents did not change much (between 16.74 and 19.02%). The botanical composition remained constant, as indicated by the percentages of grasses and legumes (Table 71).

Table 71. Botanical composition of the prairies (% of the total yield) at Mabegondo

Crop	Cropping season	Grasses	Legumes	Weeds
Short duration (F_2)	1980-81	68.01	28.16	3.82
	1981-82	61.37	37.82	0.80
	1982-83	80.98	18.31	0.70
Short duration (F_2) Rotation prairies → corn Whole year production	1980-81	51.40	48.05	0.45
	1981-82	62.65	32.64	1.98
	1982-83	60.46	36.47	3.05
Long duration (F_6)	1980-81	71.79	24.55	3.64
	1981-82	64.60	32.42	2.97
	1982-83	72.91	23.87	3.20

For comparing both types of prairies, F_2 and F_6, three years might not be enough time, and four or five years would have been better. The reason is because with more time, maybe the yield of F_2 would have decreased a little while the production of the ryegrass-white clover mixture would have been more maintained. In this case, the average mean yield for 4 to 5 years possibly would have been very similar or higher for the long-term prairie. This trend can be seen when comparing the production for 1982-83. In that year, the yields of the long-term mixture were already slightly higher than that of the F_2 (13.33 vs. 12.62 t/ha), and the quality of the F_6 was better than that of the F_2.

The comparison of these results with published data may not be very realistic because the varieties used, the species, the climatological conditions, the amount of N fertilizer, the management, etc. may be very different.

When contrasting the F_2 mixture with Italian ryegrass (12 month), the results show that the yield of the mixture is higher (13.76 vs. 12.84 t/ha) and also the protein contents (16.26 vs. 14.57%), and this might be due to the contribution of the legume; the digestibility, however, was on the average a little lower for the prairies than for the ryegrass (65.93 vs. 67.71%).

The yields for F_2 obtained in this experiment appear normal. However, Piñeiro and Perez (249) obtained a two-year mean yield of 18.5 t/ha with a mixture of Italian ryegrass-red clover. In France, some reports showed yields of 12.3 t/ha for the same association (137). The production given by the perennial ryegrass-white clover mixture in this experiment (12.15 t/ha), does not differ very much from the 11.2 t/ha reported by Gonzalez (106) with a perennial ryegrass, cocksfoot-white clover mixture at Mabegondo. Some French data (20) also reported similar yields of about 13 t/ha for the perennial ryegrass-white clover association; however, during a more ideal climate, 16.3 t/ha were obtained. In Northern Ireland, the same mixture was reported to produce about 7.68 t/ha, while in New Zealand, Ball (12) obtained about 18 t/ha without N.

The digestibility and crude protein percentages reported by different authors change much depending on the species, number of cuttings, stage of harvest, N fertilization, location, etc. Although in general, perennial ryegrass is considered the best grass and orchardgrass the worst for forage quality. The digestibilities presented in the literature for Italian ryegrass are about 75 to 80% at the leaf stage and decrease to about 60% after ear emergence, while the protein contents change from about 25% at the young stage to around 8% after heading (3, 144, 161, 204, 287). For perennial ryegrass, the reported values range from 78 to 83% digestibility at the vegetative stage to about 55 to 65% at maturity, and protein concentration from 18% at initial vegetative stage to 8-10% at flowering (3, 144, 193, 299).

The quality values for orchardgrass, mainly the digestibility, are a little lower than for the ryegrasses (258). Aldrich and Dent (3) found orchardgrass 5.5% less digestible than perennial ryegrass at the same date of heading. Other reports have presented values from 80%

digestible at vegetative stage to about 43-50% at post-flowering stage with crude protein values reported from 25.7% to about 8.5% (144, 217, 255, 285, 288, 291).

The legumes, white and red clover, normally have higher digestibility than the grasses and of course higher protein contents. The protein values reported for white and red clover change from 28% at the vegetative stage to 14% at full bloom. On the other hand, the digestibility values generally obtained are about 75%, with a change from about 80% digestibility for young plants to 61 to 67% for late cuts (49, 64, 190, 287, 302).

After this review of the quality determinations reported for the different species and also taking into account the average botanical composition of the forage (Table 71), it can be concluded that the quality of the prairies obtained at Mabegondo was satisfactory. The long-term prairies with 17.97% crude protein and 70.71% digestibility gave a good quality forage. The short-term prairies, on the other hand, produced an average quality forage, with adequate protein content. These quality determinations reflect the effects of the different species that are in the two mixtures, that is, because perennial ryegrass in general is of better quality than orchardgrass and Italian ryegrass.

The comments made about the short-term prairies are also valid for the swards of the rotation of prairies → corn, because both are of the same type. The results are quite similar, although they may not coincide because for the rotation of prairies → corn, two plots were averaged and in one of them, the prairie was 6 months older than in the short-term prairie treatment and for the other plot, the prairie was one and two years younger. On the other hand, the higher quality and lower yield presented for the prairie of the plot that will have corn in spring should be expected, because the mixture was cut at a younger stage in order to seed corn.

Analysis of the crop rotations After the individual analysis of the crops that enter in the crop rotations, the next and important step is the calculation and examination of the rotation itself with all its components. The average yearly total dry matter, crude protein and digestibility percentages and the ANOVA are presented in Table 72. A more detailed summary of the dry matter yields of the different rotations for each cropping season is given in Table 73. The analysis of variance shows significant differences among rotations and cropping seasons.

From Table 72, it is clear that the dry matter production per unit of land increases with increasing cropping intensity. The rotations which have two crops per year (corn → rye, corn → oats + vetch, and corn → Italian ryegrass) had higher forage yield than the others, although the ANOVA did not always show significant differences. The rota- corn → oats + vetch gave the highest yields with 19.70 t/ha, followed by the corn → rye with 18.28 t/ha and corn → Italian ryegrass with 17.14 t/ha.

The next lower step in amount of production came with the less intensive rotations of corn → Italian ryegrass → rape (three crops in two years) which gave an average of 16.57 t/ha, and the rotation of prairies

Table 72. Annual average crop rotation dry matter yields, CP, IVDMD and the ANOVA at Mabegondo (1980-83)

Crop rotation	DM (t/ha)	CP	IVDMD
1. Corn	13.46	6.45	71.39
2. Corn → rye	18.28	8.74	71.27
3. Corn → oats + vetch	19.70	9.88	71.40
4. Corn → Italian ryegrass	17.14	8.19	73.30
5. Corn → Italian ryegrass → rape	16.57	10.69	71.53
6. Prairies → corn	16.06	13.28	67.63
7. Prairies (short duration)	13.76	16.26	65.93
8. Prairies (long duration)	12.15	17.97	70.71
LSD (0.05)	2.79		

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Blocks	5	38.66	0.46	0.1129
Rotation	7	841.60	7.09	0.0001
Block*Rotation	35	593.64	--	--
Crop season	2	221.34	26.38	0.0001
Rotation*Crop season	14	103.84	1.77	0.0583
Error	80	335.63	--	--

Table 73. Dry matter yields for cropping season and dry matter yields of the crop rotations at each cropping season (1980-83) at Mabegondo

Cropping season	DM (t/ha)
1. 1980-81	14.21
2. 1981-82	17.18
3. 1982-83	16.28
LSD (0.05)	0.83

Crop rotation	Cropping season	DM (t/ha)
1. Corn	1	10.65
	2	14.51
	3	15.22
2. Corn → rye	1	16.36
	2	19.85
	3	18.64
3. Corn → oats + vetch	1	17.74
	2	21.12
	3	20.26
4. Corn → Italian ryegrass	1	16.53
	2	16.78
	3	18.10
5. Corn → Italian ryegrass → rape	1	15.47
	2	19.04
	3	15.19
6. Prairies → corn	1	14.09
	2	17.20
	3	16.90
7. Prairies (short duration)	1	12.93
	2	15.73
	3	12.62
8. Prairies (long duration)	1	9.96
	2	13.17
	3	13.33
	Mean	15.89

(two years) → corn yielded 16.06 t/ha. Finally, the least intensive rotations, corn (monocropped) and prairies produced between 12.15 and 13.76 t/ha.

The results also show that corn is the main intensification factor. The advantage of corn is not only that it is the highest yielding crop in the shortest period of time but also that it allows double cropping, and the additional winter forage which is obtained is what makes the double cropping systems more productive. Another interesting point is the fact that short duration prairies and monocropped corn yielded similarly.

Before continuing with an analysis of the rotations, it has to be clear that in this study no economic aspects were included, although these are the most important factors if a particular rotation has to be chosen for a particular farm.

The quality of the forage produced is given by the crude protein and the digestibility. From an examination of Tables 68, 69 and 72, it is clear that corn compared with prairies is similar or more digestible (71.39%) than the forage of the short-term prairie (65.93%) and similar to the long-term mixtures (70.71%). However, the crude protein contents of corn were the lowest (6.45%) of any of the crops included in the rotation. These numbers are very important in the total quality of the rotation since corn accounts for about 70% of the total dry matter production of the double cropping systems.

Comparing the rotations which include corn with short- and long-term prairies, the rotations with corn had higher digestibilities than the short-term prairies and similar to the long-term prairies, but on the other hand, the crude protein contents decreased with frequency of corn in the rotation. It is not easy to decide which rotation is the best, because economic and sociological conditions are sometimes more important than the forage yield, but considering only the total yield and quality, the corn → oats + vetch is the more appropriate if an intensification of the production is needed in Mabegondo. If no intensification is needed, the perennial ryegrass-white clover mixture produced a good amount of high quality forage.

Puebla de Brollon

The final total dry matter yields for each rotation, the CP, IVDMD values and the ANOVA table for the rotations are presented in Table 78. A summary of the dry matter yields for each cropping season is given in Table 79. Finally, a detailed exposition of the yields and quality determinations of the different crops throughout the duration of the experiment is shown in Tables 74 and 75. In order to follow the same scheme in all locations, each crop will be examined first and the crop rotations will be analyzed later.

Analysis of crop yields and quality

Corn The dry matter yields, ear/total plant ratio, CP, ADF, and IVDMD values are given in Table 74. The average dry matter yields varied much depending on years. In 1981 and 1982, the production was similar with 8.85 and 9.70 t/ha, respectively; however, in 1983 an excellent August rainfall increased yields to 15.84 t/ha. At Puebla de Brollon, the summers are normally rather dry with very little rainfall

Table 74. Average dry matter yield (t/ha) and percentages of CP, ADF and IVDMD of corn in different rotations and years at Puebla de Brollon

Year	Rotation	D.M.	(Ear/total plant) x 100	CP	ADF	IVDMD	Density (plant/ha)
1981	Corn	7.80	31.15	6.77	29.72		
	C→rye	9.19	29.30	7.42	30.52	61.83	
	C→oats + v.	8.26	26.54	9.16	32.33		
	C→It. ryegrass	9.25	32.86	6.77	30.11	60.56	
	C→It. rye→rape	9.53	31.26	8.31	29.91	62.85	
	Pastures→C	9.09	34.76	8.97	30.07		
Average		8.85	30.98	7.90	30.44	61.74	99,666
1982	Corn	9.71	41.09	6.70	26.16	67.88	
	C→rye	10.05	42.48	6.84	24.81		
	C→oats + v.	8.70	39.54	7.42	26.53	64.59	
	C→It. ryegrass	11.63	45.28	6.80	25.18		
	C→It. rye→rape	9.04	44.36	7.53	22.04	70.37	
	Pastures→C	9.09	42.57	7.70	23.89		
Average		9.70	42.55	7.16	24.76	67.61	88,583
1983	Corn	15.95	49.45	7.92	27.86	68.44	
	C→rye	14.84	48.41	8.03	25.88	67.75	
	C→oats + v.	13.71	49.61	8.42	27.60	67.67	
	C→It. ryegrass	17.36	44.12	7.13	30.40	64.14	
	C→It. rye→rape	17.45	49.34	7.42	27.23	68.94	
	Pastures→C	15.75	49.57	8.02	28.69	62.95	
Average		15.84	48.41	7.82	27.94	66.65	88,499
Average 1981-83							
	Corn	11.16	40.56				
	C→rye	11.36	40.06				
	C→oats + v.	10.23	38.56				
	C→It. ryegrass	12.75	40.75				
	C→It. rye→rape	12.01	41.65				
	Pastures→C	11.31	42.30				
Average		11.47	40.64	7.62	27.71	65.33	92,249
ANOVA		n.s.					

during July, August and the beginning of September; however, in 1983 a rainy summer was the main thing responsible for the high corn yields. At the same time, the ear/total plant ratio increased to 48.41% compared with 42.55% in 1982 and 30.98% in 1981. The corn yields in 1981 and 1982 can be classified as poor, but this should be considered normal for this dry and hot summer area. Also, the high yields in 1983 provide an estimate of the production potential of the area when irrigation is provided. These 1983 yields could possibly have been higher if the heavy spring rainfall had not delayed seeding time until June 7. The average date is about the first week of May.

Compared with Mabegondo, the dry matter yields are lower, except for 1983, because of the difference in climate at the two locations. The digestibilities at Puebla were also lower than at Mabegondo, and the cause might be the lower ear/total plant ratios at Puebla where the maximum was about 48.41% in 1983 while at Mabegondo the lowest was 50.58% in 1981. The lower ear/total plant proportion at Puebla could be due to the poor climatic conditions for this location and also due to a difference in hybrid used. The crude protein contents, however, were superior at Puebla de Brollon, which may be reflecting the different climate, the better soil (Table 93), different hybrid, and the water stress conditions of the location. As at Mabegondo, the ANOVA for Puebla de Brollon did not find significant differences among corn yields in the different rotations although at this location the corn double cropped with oats + vetch yielded the lowest, 10.23 t/ha, while corn following Italian ryegrass (6 months) gave the highest, 12.75 t/ha.

The most likely explanation is soil heterogeneity which in the absence of rain showed very different water-holding capacities, maybe due to the differences in soil depth. These soils might have averaged being poorer for the plots for the corn → oats + vetch rotation. In general, the crop in Puebla de Brollon was poor, with average crude protein and with digestibilities in the lower range of the normally reported values.

Rye The average dry matter yields were 4.71 t/ha, with 16.62% crude protein and 71.86% digestibility (Table 75). These values are very similar to the ones obtained at Mabegondo (4.46 t/ha, 16.01% CP and 71.50% IVDMD). However, at Puebla the yearly quality variations were less than at Mabegondo although the dry matter yields were more variable (from 3.78 to 5.58 t/ha at Puebla and 3.79 to 4.87 t/ha at Mabegondo). The higher yields in 1981 might be due to the higher March temperatures during 1981 compared with 1982 and 1983. On the other hand, the low yields in 1983 could be because of late seeding date in the fall of 1982 (October 20) compared with the normal seeding time (first week of October) and in the fall a two-week delay makes a lot of difference in growth.

As it was concluded for Mabegondo, rye at Puebla de Brollon produced a fair amount of good quality forage .

Oats and vetch The average dry matter yields were 4.88 t/ha with a crude protein percentage of 21.68% and a 72.16% digestibility (Table 75). These values are similar to those reported for Mabegondo (5.22 t/ha, 19.42% crude protein and 71.43% digestibility). The differences are that at Puebla the dry matter production was a little

Table 75. Average dry matter yields (t/ha) and percentages of CP, ADF and IVDMD of the crops at the different cropping seasons at Puebla de Brollon

Crop	Cropping season	DM	CP	ADF	IVDMD
Rye	1980-81	5.58	23.18	31.54	69.50
	1981-82	4.78	12.24	30.04	73.92
	1982-83	3.78	14.45	29.62	72.18
	Average	4.71	16.62	30.40	71.86
Oats+vetch	1980-81	4.98	22.72	30.34	71.69
	1981-82	5.07	26.13	29.81	73.13
	1982-83	4.59	16.20	30.09	71.66
	Average	4.88	21.68	30.08	72.16
It. ryegrass (6 months)	1980-81	4.16	20.60	23.00	78.04
	1981-82	4.57	16.36	26.66	70.14
	1982-83	3.15	11.25	24.65	78.82
	Average	3.96	16.07	24.77	75.66
It. ryegrass (12 months)	1980-81	10.40	18.74	28.46	71.13
	1981-82	9.02	10.54	36.44	58.44
	1982-83	9.51	8.61	34.76	64.21
	Average	9.64	12.63	32.22	64.59
Rape	1980-81	5.12	19.06	27.21	75.60
	1981-82	8.56	11.59	30.90	74.95
	1982-83	3.22	11.86	25.33	81.44
	Average	5.63	14.17	27.81	77.33
Prairies (short duration)					
Rot. Prairies → corn					
a. Whole year production (mean of two plots)	1980-81	9.81	15.04	31.96	67.80
	1981-82	11.86	14.22	31.63	66.52
	1982-83	11.54	12.36	35.50	63.05
	Average	11.07	13.87	33.03	65.79
b. From fall until corn seeding of the plot that will carry corn	1980-81	3.35	20.35	25.73	72.07
	1981-82	7.22	15.93	26.06	74.02
	1982-83	3.20	21.20	28.36	67.93
	Average	4.59	19.16	26.71	71.34
Prairies (short)	1980-81	9.34	14.82	31.21	68.00
	1981-82	11.32	15.43	29.69	69.43
	1982-83	10.92	10.04	37.30	52.82
	Average	10.53	13.43	32.73	63.41

lower while the quality was a little higher, maybe reflecting the inverse relationship between quantity and quality. It is also interesting to notice that at Puebla the dry matter productions and qualities were quite constant in all three years. The variations in crude protein percentages might be mainly due to N application timing, and also in the winter of 1981-82 the crop was cut twice, once in December because of some lodging and its regrowth in April.

Since the yields and digestibilities of rye and oats with vetch at Puebla were very similar, the conclusions cannot greatly differ. The only difference is that the mixture of oats and vetch was higher in protein than rye (21.68 vs. 16.62%, respectively) which reflected the beneficial effect of the legume in the mixture.

Italian ryegrass The results found in Puebla de Brollon show an average dry matter production of 3.96 t/ha for the ryegrass seeded in fall and harvested before corn (ryegrass 6 months) and 9.64 t/ha for the crop seeded in the fall after corn and plowed under the next fall before the rape (12 months) (Table 75).

For the ryegrass (6 months), the dry matter yields in 1981 and 1982 were very similar (4.16 and 4.57 t/ha) and higher than in 1983 (3.15 t/ha), the reason could be the late seeding date in the fall of 1982 (October 20) compared with the normal time during the first week of October.

The average dry matter production was a little higher at Mabegondo (4.29 t/ha) than in Puebla (3.96 t/ha); however, the difference was mainly in 1983, because the productions in 1981 and 1982 were very similar. The average digestibility also was higher at Mabegondo (79.03%) compared with 75.66% at Puebla, while the opposite was true for crude protein (16.07% at Puebla vs. 13.48% at Mabegondo). The protein and digestibility were very similar for both locations in 1981 and 1983, but differed in 1982 where the crop at Puebla had higher crude protein contents and lower digestibilities. The protein variation could be partially explained by differences in N fertilization timing, while the lower digestibility coincided with higher dry matter yields, meaning that the crop might have been harvested at a later development stage. In general, although the quality was a little lower than in Mabegondo, the crop still produced a more digestible forage than oats and vetch or rye, however with a lower dry matter production.

Although the production for ryegrass (6 months) was very similar at both locations, the production of ryegrass (12 months) at Puebla (9.64 t/ha) was much lower than at Mabegondo (12.84 t/ha). The different summer climates at the two locations, hot and dry in Puebla and milder at Mabegondo, explain the discrepancy. During the summer, the high temperatures (Appendix A) and the usual drought are not very appropriate growth conditions for this crop, and the regrowths after heading were normally very poor. The quality aspects of the crop, protein and digestibility, were also lower than at Mabegondo, reflecting the poor growth conditions; in order to get meaningful yields, the crop was harvested at more mature stage at Puebla. Several papers present digestibilities of about 60 to 65% after ear emergence (3, 144, 287).

Compared with the winter crops, the ryegrass (12 months) was a lower quality crop (64.59% digestibility and 12.63% crude protein), but very similar to or better than corn (65.33% digestibility and 7.62% crude protein), which probably shows the poor growing conditions for the crops grown during the summer at Puebla de Brollon.

Comparison of the winter crops after corn (rye, oats with vetch and Italian ryegrass, 6 months) The analysis of variance of the dry matter yields presented in Table 76 shows significant differences

Table 76. Analysis of variance of the comparison of the dry matter production of the winter crops (rye, oats+vetch and Italian ryegrass) after corn at Puebla (1980-83)

Crop	Production (t/ha)
Rye	4.71
Oats + vetch	4.88
Italian ryegrass	3.96
LSD (0.05)	0.61

Crop season	Production (t/ha)
1980-81	4.91
1981-82	4.81
1982-83	3.84
LSD (0.05)	0.46

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Rep	5	9.71	2.83	0.0759
Crop	2	8.59	6.27	0.0172
Rep*Crop	10	6.86	--	--
Crop season	2	12.58	13.89	0.0001
Crop season*Crop	4	4.50	2.49	0.0644
Error	30	13.59	--	--

among crops and cropping seasons. The Italian ryegrass (3.96 t/ha) yielded less than oats with vetch (4.88 t/ha) and rye (4.71 t/ha).

If a crop is chosen in terms of quality and quantity, oats with vetch is more appropriate because it yields as much as rye with similar digestibilities, while its crude protein content is much higher, and the yields were more uniform. However, if the crop is to be used for pasture with heavy amounts of N fertilizer, maybe Italian ryegrass would be preferred.

<u>Forage rape</u> The average dry matter yields (5.63 t/ha), the crude protein contents (14.17%) and the digestibility (77.33%) are presented in Table 75. Compared with the other winter crops, the average dry matter production was higher than rye (4.71 t/ha), oats with vetch (4.88 t/ha) and Italian ryegrass (3.96 t/ha), mainly because of the high production in 1982 (8.56 t/ha). Early fall seeding in 1981 and late cutting in 1982 might have been the reasons for this high yield. In the fall of 1982, the seeding was late and in 1983 the yields were the lowest of the three years (3.22 t/ha).

Compared with Mabegondo, the yields were a little higher in Puebla (5.63 vs. 5.26 t/ha) as was the crude protein content (14.17 vs. 13.40%), while the digestibility was lower (77.33 vs. 81.55%). There is no straight forward explanation with the available data to explain these differences. The most logical reasons could be the timing of the N applications, the better soil at Puebla and experimental error. On the other hand, the lower digestibility could be explained in the sense that the higher yields, mainly in 1981 and 1982, were obtained because of harvesting the crop at a more mature stage.

An important advantage for forage rape is that, as at Mabegondo, it was the most digestible crop. The yields and qualities at Puebla are similar with other values reported from several countries (99, 143, 277).

Short-term prairies At Puebla de Brollon, short- and long-term mixtures were seeded; however, the long-term association of perennial ryegrass and white clover did not establish well and was not included in the experiment. This is the reason why this type of prairie is not going to be analyzed at Puebla. But it is interesting to point out that some of the plots seeded 1980 and reseeded in 1981 established ground cover and had good production in the spring of 1983.

The short-term mixture (F_2) had an average production at Puebla of 10.53 t/ha (Table 75). This yield is much lower than at Mabegondo (13.76 t/ha) and the reasons are chiefly climatological because the winters are much cooler and the summers hotter and drier at Puebla, which makes this location less suitable for production by the prairies. The average production of the prairies in the rotation of prairies → corn was also about 3 t/ha less than the similar swards at Mabegondo (11.07 t/ha compared with 13.76 t/ha).

The yields of the F_2 from fall until corn seeding were similar in both locations, 4.96 t/ha at Mabegondo and 4.59 t/ha at Puebla; the quality measurements also were similar. This is normal since this yield is really the spring yield; as with the annual winter crops, their average productions were very similar at both locations.

As it was previously mentioned for Mabegondo, composition of the F_2 prairie normally changes with age. Italian ryegrass and red clover disappear and orchardgrass becomes the dominant species, at least for nonpasture situations. The botanical composition is presented in Table 77, which shows that effect. During the first two years, the

Table 77. Botanical composition of the prairies (% of the total yield) at Puebla de Brollon

Crop	Cropping season	Grasses	Legumes	Weeds
Short duration (F_2)	1980-81	79.25	12.70	8.04
	1981-82	77.31	20.31	2.36
	1982-83	92.21	4.15	3.62
Short duration (F_2)				
Rotation prairies → corn	1980-81	78.86	11.17	9.95
Whole year production	1981-82	76.57	19.64	3.78
	1982-83	78.87	18.69	5.09

legume content was between 12.70 and 20.31% while by the third year it was 4.15%. The quality determinations also reflected this fact; the crude protein contents decreased from about 15% in the first two years to 10.04% for the third, while ADF increased from about 30% to 37.30% and the digestibility dropped from 68 to 69% to 52.82%. All these factors indicate the decrease in quality of the mixture was greater at Puebla than at Mabegondo.

At Puebla, as happened at Mabegondo, the production of the F_2 was a little higher than that of Italian ryegrass (12 month) (10.53 vs. 9.64 t/ha), as was true for crude protein (13.43 vs. 12.63%); however, the mean digestibility was a little lower than for the ryegrass (63.41 vs. 64.59%). The somewhat higher yields and quality of the F_2 of the rotation prairies → corn, compared with the F_2 for three years is logical, because although in 1981 both prairies had exactly the same age (all of them were seeded in the fall of 1980), in 1982 and 1983 the plots of the prairies → corn rotation, as an average, were younger (every year a different plot of prairie was plowed under, seeded with corn and seeded again after corn).

The analysis of the F_2 prairies at Puebla can be summarized by saying that the lower yield and slightly reduced quality compared with Mabegondo reflect the more extreme growing conditions at Puebla. On the other hand, the quality of the whole year's crop is about the quality of the Italian ryegrass at heading; however, the spring cut represented by the production of the plots that will be seeded with corn is of much higher quality.

Analysis of the crop rotations The average yearly total dry matter yields, crude protein and digestibility percentages and the ANOVA are presented in Table 78. A more detailed summary of the dry matter yields of the different rotations in each cropping season is given in Table 79. The analysis of variance shows significant differences among rotations and cropping seasons.

The analysis of the production of the crop rotations in Puebla show very similar trends to that at Mabegondo. It is clear that the dry matter production per ha increases with increasing the cropping intensity. As at Mabegondo, the rotations that have two crops per

Table 78. Annual average crop rotation dry matter yields, CP, IVDMD and the ANOVA at Puebla de Brollon (1980-83)

Crop rotation	DM (t/ha)	CP (%)	IVDMD (%)
1. Corn	11.16	7.62	65.33
2. Corn → rye	16.08	10.25	67.20
3. Corn → oats + vetch	15.11	12.15	67.49
4. Corn → Italian ryegrass	16.71	9.61	67.74
5. Corn → Italian ryegrass→rape	13.64	10.74	67.52
6. Prairies → corn	12.73	10.30	66.32
7. Prairies (short duration)	10.53	10.53	63.41
LSD (0.05)	2.65		

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Blocks	5	183.49	2.42	0.059
Rotation	6	615.31	6.75	0.0001
Block*Rotation	30	455.81	--	--
Crop season	2	448.74	75.23	0.0001
Rotation*Crop season	12	148.30	4.14	0.0001
Error	70	208.76	--	--

Table 79. Dry matter yields of the cropping seasons and dry matter yields of the crop rotations at each cropping season at Puebla de Brollon (1980-83)

Cropping season	DM (t/ha)
1. 1980-81	11.68
2. 1981-82	13.21
3. 1982-83	16.23
LSD (0.05)	0.75

Crop rotation	Cropping season	DM (t/ha)
1. Corn	1	7.80
	2	9.71
	3	15.96
2. Corn → rye	1	14.77
	2	14.83
	3	18.63
3. Corn → oats + vetch	1	13.24
	2	13.77
	3	18.30
4. Corn → Italian ryegrass	1	13.41
	2	16.21
	3	20.52
5. Corn → Italian ryegrass → rape	1	12.53
	2	13.31
	3	15.09
6. Prairies → corn	1	10.69
	2	13.35
	3	14.17
7. Prairies (short duration)	1	9.33
	2	11.32
	3	10.92
	Average	13.71

year (corn → rye, corn → oats with vetch and corn → Italian ryegrass) had higher yields, although not always significant according to the ANOVA. The rotation of corn → Italian ryegrass gave the highest yield with 16.71 t/ha followed by corn → rye with 16.08 t/ha and corn → oats with vetch with 15.11 t/ha. Compared with Mabegondo, the rotation of corn → Italian ryegrass and corn → oats + vetch interchanged ranks. The main reason was because the corn yields for the corn → oats + vetch rotation were a little higher than for other rotations while at Puebla that yield of corn was the lowest.

The next lower level of production came with less intensive rotations. Corn → Italian ryegrass → rape (three crops in two years) produced an average of 13.64 t/ha and prairies (two years) → corn yielded 12.73 t/ha. At Mabegondo, the relative portion of both rotations was the same although the yields were more similar (16.57 and 16.06 t/ha). In Puebla, the relatively high yield of forage rape compared with corn and Italian ryegrass (12 months) made the differences larger. Finally, the least intensive rotations, corn (monocropped) and prairies, produced an average of 11.16 and 10.53 t/ha.

Comparing the two locations, the average yearly yields at Mabegondo are about 3 t/ha higher than at Puebla. The reason is again the hot and dry summer growing conditions in nonirrigated fields at Puebla. The yields of the winter crops, as it has been previously analyzed, were similar; but the yields of the crops in summer were higher at Mabegondo. Analyzing the average production of the cropping seasons, at Puebla (Table 79) the yield in 1982-83 was 16.23 t/ha, which was 3 to 4.5 t/ha higher than for 1980-81 and 1981-82 cropping seasons. During 1982-83, high summer rainfall increased corn yields by 6 t/ha above normal, which was more than enough to compensate for the previous lower yields of the winter crops and to raise the total production of the rotations. During the 1982-83 cropping season, the average yields were very similar for both locations, 16.23 t/ha at Puebla and 16.28 t/ha at Mabegondo (including the F_6 prairie, with a 13.33 t/ha yield). Although corn did not yield as much as at Mabegondo, this crop was also the main intensification factor, causing greater production for double cropping.

Another interesting similarity in both locations is that the dry matter yields of the short duration prairies (10.53 t/ha) and corn (11.16 t/ha) were similar, although at Puebla the quality of corn compared with prairies was more similar. Corn had an average of 65.33% digestibility and prairies 63.41%, while at Mabegondo the respective values were 71.39% and 65.93%. On the other hand, the crude protein percentages were 16.26 for the F_2 prairies and 6.45 for corn. At Puebla, the contents were 10.53% for the prairies and 7.62% for corn. Since at Puebla the relative yields of the winter crops compared with corn are higher and the quality of these crops is also better than corn, their inclusion on a double cropping system with corn had a more beneficial effect on the quality of the whole rotation than in Mabegondo.

The best rotation for each farm depends on many economic and social factors, but if high dry matter yields are required, the more intensive double cropping systems provide the highest yields. On the other hand, the prairies could be the most appropriate crop in nonintensive situations.

Arzua

The final total dry matter yields for each rotation and their CP and IVDMD contents and the ANOVA are presented in Table 84. A summary of the dry matter yields for each cropping season is given in Table 85. Finally, a detailed exposition of the yields and quality determinations of the crops during the duration of the experiment is shown in Tables 80 and 81.

At Arzua, the comparisons among crop rotations and pastures are going to be reduced only to the 1981-82 and 1982-83 cropping seasons. The reason is because corn in 1981 was severely damaged by insects and birds and the yields were not representative of the potential of the area. However, when analyzing each crop by itself, all three years of data will be presented when available.

A problem at Arzua is the lack of certain IVDMD values for some cuttings and crops (about 1/3 of the total number of samples). In this case, the digestibilities used were calculated through prediction equations, based on the crude protein and acid detergent fiber contents of the samples. The prediction equations for each crop were calculated using all the data from the four locations in which CP, ADF and IVDMD values were available. The presentation of the IVDMD percentages help to give a better idea of the quality of the crop, although in Arzua the values should be used with caution for the above reasons. The prediction equations which were used are presented in Appendix C.

Table 80. Average dry matter yield (t/ha) and percentages of CP, ADF and IVDMD of corn in different rotations and years at Arzua

Year	Rotation	D.M.	(Ear/total plant) x 100	CP	ADF	IVDMD[a]	Density (plant/ha)
1982	Corn	12.99	52.11	5.56	24.66		
	C→rye	10.23	40.17	6.11	25.18		
	C→oats+vetch	11.39	42.31	6.45	25.09		
	C→It. ryegrass	9.18	42.71	6.33	23.57		
	C→It. rye→rape	9.04	42.23	6.70	23.66		
	Pasture→C	11.29	42.42	6.70	24.47		
Average		10.68	43.66	6.31	24.44	67.82	106,302
1983	Corn	9.95	51.85				
	C→rye	10.27	48.10				
	C→oats+vetch	14.04	48.35				
	C→It. ryegrass	11.01	49.41				
	C→It. rye→rape	10.24	51.98				
	Pasture→C	12.33	48.24				
Average		11.30	49.65				75,381
Average 1982-83							
	Corn	11.47	51.98				
	Corn→rye	10.25	44.13				
	C→oats+vetch	12.71	45.33				
	C→It. ryegrass	10.09	46.06				
	C→It. rye→rape	9.64	47.10				
	Pasture→C	11.81	45.33				
Average		10.99	46.65	6.31	24.44	24.44	90,841
LSD (0.05)		1.27					

[a]The IVDMD was calculated through regression equations.

<u>Analysis of crop yields and quality</u>

<u>Corn</u> Only two years of data were available for corn at Arzua. The 1981 crop was discarded because of bird and insect damage. The dry matter yields, ear/total plant ratio, CP, ADF and IVDMD values are given in Table 80. The crude protein and fiber contents of the plant were only available for the 1982 crop, and the digestibility values were calculated by prediction equations.

The average dry matter yields varied very little for the two years (10.68 t/ha in 1982 and 11.30 t/ha in 1983). These yields are about 3 t/ha lower than at Mabegondo and a little higher than at Puebla in 1982 (10.68 vs. 9.70 t/ha) but much lower than in this location in 1982 (11.30 vs. 15.84 t/ha). The reason is because Arzua compared with Mabegondo has a similar rainfall pattern during the summer, but Arzua is about 400 m above sea level and this makes it cooler with a shorter growing season for corn. The spring temperatures are generally lower (April and May) and the seeding time for corn is normally delayed 10-15 days compared with Mabegondo. Another reason for the lower yields is the soil pH (5.40) and quality (Table 94) generally is inferior to the other locations. The yields in 1983 would have probably been higher if a rootworm attack had not decreased the initial density.

The ear/total plant ratio for 1982 and 1983 was lower than at Mabegondo and very similar to that at Puebla de Brollon. The predicted digestibilities were also similar to those at Puebla for 1982, although the crude protein was lower but similar to that at Mabegondo. The lower average yields at Arzua reflect the shorter growing season and the poorer soil of the area compared with the other two locations. On the other hand, a good point is that the yields were very uniform from one year to the next.

Another difference for Arzua, compared with Mabegondo and Puebla, is that the ANOVA showed significant differences for the corn yields of the different rotations. The production of corn in the rotation of corn → oats with vetch (12.71 t/ha) was the highest, while the lowest were rotations of corn → Italian ryegrass → rape (9.64 t/ha) and corn → Italian ryegrass (10.09 t/ha). These results have several similarities with Mabegondo but not with Puebla. At Mabegondo, the corn of the corn → oats + vetch rotation gave one of the highest yields, and the corn → Italian ryegrass rotation the lowest corn yield. There is no clear explanation for all these variations among treatments and locations. One possible explanation for the higher yields of the rotation corn → oats + vetch could be that oats with the vetch crop received lime every year at seeding time and this dressing, as it is shown by the soil analysis (Tables 3 and 94) raised the pH of the plots and reduced the ratio Al/CEC down to 0.11 compared with about 0.30 for other rotations, thus decreasing the risk of Al toxicity (305). This could partially explain some yield differences. Variations in plant density and the experimental error can also account for variation.

<u>Rye</u> The average dry matter yields and the quality determinations are presented in Table 81. The dry matter yields (5.13 t/ha) were a little higher than at Mabegondo and Puebla (4.46 and 4.71 t/ha, respectively); however, the quality was clearly lower. The crude protein at

Table 81. Average dry matter yields (t/ha) and percentages of CP, ADF and IVDMD[a] of the crops at different cropping seasons[b] at Arzua

Crop	Cropping season	DM	CP	ADF	IVDMD
Rye	1980-81	5.05	17.09	35.40	67.82
	1981-82	4.35	10.45	30.20	71.98
	1982-83	6.01	6.58	39.86	58.40
	Average	5.13	11.37	35.15	66.06
Oats + vetch	1980-81	5.52	15.43	34.22	67.15
	1981-82	10.46	11.22	32.95	70.06
	1982-83	5.97	9.80	30.94	66.96
	Average	7.31	12.15	32.70	68.05
It. ryegrass (6 months)	1980-81	2.66	14.92	26.71	75.14
	1981-82	4.44	8.26	21.89	78.42
	1982-83	0.86	9.42	22.43	79.31
	Average	2.65	10.86	23.67	77.62
It. ryegrass (12 months)	1980-81	7.39	14.54	32.00	64.67
	1981-82	10.29	9.13	28.40	69.81
	1982-83	5.99	12.09	31.13	62.31
	Average	7.89	11.92	30.51	65.60
Rape	1980-81	0.00	--	--	--
	1981-82	2.90	11.18	24.85	82.24
	1982-83	0.63	10.82	28.28	74.96
	Average	1.17	11.00	26.56	78.60
Prairies (short duration)					
Rot. Prairies → corn					
a. Whole year production (mean of two plots)	1980-81	8.61	15.24	33.84	62.10
	1981-82	10.57	12.48	31.75	68.98
	1982-83	10.64	14.47	33.40	60.56
	Average	9.94	14.06	32.99	63.88
b. From fall until corn seeding of the plot that will carry corn	1980-81	2.61	21.28	31.12	--
	1981-82	2.29	18.49	26.85	67.82
	1982-83	2.98	18.70	25.84	71.38
	Average	2.62	19.49	27.93	69.60

[a]Some IVDMD values were calculated using predicting equations.

[b]Only the results from 1981-82 and 1982-83 will be used for the ANOVA, because corn was severely damaged in 1981.

Table 81. (Continued)

Crop	Cropping season	DM	CP	ADF	IVDMD
Prairies (short)	1980-81	9.22	13.17	31.11	69.73
	1981-82	11.03	16.79	30.68	65.59
	1982-83	11.05	14.98	34.98	60.07
	Average	10.43	14.98	32.25	65.13
Prairies (long)	1980-81	7.50	15.36	33.67	69.03
	1981-82	8.67	13.65	28.50	68.88
	1982-83	11.77	13.30	31.48	65.66
	Average	9.31	14.10	30.92	67.86

Arzua was 11.37%, while at Mabegondo and Puebla the values were more than 16%. The same was true for the digestibility, since at Puebla and Mabegondo it was about 71%, while at Arzua it was 66.06%.

The higher yields and lower qualities in 1983 were due to late harvesting, forced by continuous spring rains. In that year, the crop was cut at the post-heading stage, while in the other two years it was at the boot stage. The generally low quality at Arzua with similar yields at all three locations give an indication that the crop was harvested at a more mature stage at Arzua and also that the growing conditions, winter and spring temperatures, soil quality, etc. were poorer.

The crude protein and digestibilities obtained at Arzua are in the normal range of values reported (53, 86, 155, 200) near the heading stage and of the same average digestibilities as the F_2 prairies at Puebla de Brollon.

<u>Oats with vetch</u> The average dry matter yield was 7.31 t/ha, with an average crude protein of 12.15% and with a 68.05% digestibility (Table 81). The production in Arzua was much higher than at Mabegondo or Puebla (5.22 and 4.88 t/ha, respectively). Every year the productions were always superior at Arzua, but the big difference was in 1982, in which the dry matter yield was 10.46 t/ha at Arzua compared with 6.32 t/ha at Mabegondo and 5.07 t/ha at Puebla. However, as normally happens, production and quality were inversely proportional and the protein and digestibility were lower at Arzua (10.46 and 70.06%, respectively) than at Mabegondo (21.30 and 76.84%) or Puebla (26.13 and 73.13%). The main reasons for the yield supericrity at Arzua may be the somewhat longer season for the crop compared with the other locations, and less lodging. It was stated in the Materials and Methods section that corn had preference over all other crops at seeding time, and since the planting time was normally 10-15 days later than at Mabegondo or Puebla, and the winter crops had more time to grow in the spring. On the other hand, the cooler winter temperatures and the poorer quality soil reduced the winter growth and the mixture never lodged at Arzua, while it did during two years at Mabegondo and one at Puebla, and although after lodging vetch could grow better, these winter harvestings might have reduced the yields.

The much lower protein contents at Arzua (12.15%) compared with 19.42% at Mabegondo and 21.68% at Puebla could be due to the different spring temperatures at the locations and the relatively high temperature needs for vetch compared with oats. At Arzua, the mixture never lodged, and on the other hand, the spring temperatures might have been more beneficial for the oats than for the vetch; and for this reason, vetch never became a large proportion of the total crop and consequently did not appreciable increase the protein contents. However, at Mabegondo and Puebla the crop lodged and the proportion of vetch in the regrowth was large because of little competition from the oats. Also at this location, the spring temperatures increased sooner which allowed the legume to compete better with the grass.

In general, the mixture produced, at Arzua, a large quantity of fair quality forage.

Italian ryegrass The average yields found at Arzua were 2.65 t/ha for the ryegrass (6 month) and 7.89 for the ryegrass (12 months) (Table 81). For the ryegrass (6 month), the yields varied much during the different years, ranging from 4.44 t/ha in 1982 to 0.86 t/ha in 1983. These low yields in 1983 were due to late seeding in 1982, which was caused by persistent rainfall. The seeding was delayed more than three weeks (23 October), and this affected ryegrass more than the other winter crops because it is considered to be more sensitive to cold temperatures. Compared with the other locations, the yields at Arzua (2.65 t/ha) were much lower than at Mabegondo (4.29 t/ha) or Puebla (3.96 t/ha). The digestibility of the crop (77.62%), however, was in between Puebla (75.66%) and Mabegondo (79.03%), although the protein content was poorer (10.86% at Arzua, 13.48% at Mabegondo, and 16.07% at Puebla).

It appears that Italian ryegrass is not a well-adapted crop for winter forage production at Arzua. The production of the Italian ryegrass (12 month) was also lower at Arzua (7.89 t/ha) than at the other locations (12.84 t/ha at Mabegondo and 9.64 at Puebla). The different weather pattern and the poorer soil quality might have been the main factors for this low yield. The quality of the crop, on the other hand, was very similar in all three locations. At Arzua, the digestibility was 65.60%, at Mabegondo 67.71% and 64.59% at Puebla while the protein contents were 11.92% at Arzua, 14.57% at Mabegondo and 12.63% at Puebla.

Comparing the ryegrass (6 month) with ryegrass (12 month), the digestibility of the first (77.62%) is much higher than for the second (65.60%), indicating a younger harvesting stage for the ryegrass (6 month).

Compared with corn, Italian ryegrass (12 month) gave in general less yield (7.89 vs. 10.99 t/ha) with similar digestibilities (65.60 and 67.82%) but with higher protein (11.92 vs. 6.31%). However, during a good year (1982), the ryegrass yielded 10.29 t/ha, which was as much as corn (10.68 t/ha). This pattern was very similar to that at the other locations.

Comparison of the winter crops after corn (rye, oats with vetch and Italian ryegrass, 6 months) The analysis of variance of the dry matter yields presented in Table 82 showed significant differences among crops and cropping seasons. The oats and vetch mixture yielded more (7.32 t/ha) than rye (5.14 t/ha) and both more than Italian ryegrass (2.65 t/ha).

Table 82. Analysis of variance of the comparison of the dry matter production of the winter crops (rye, oats + vetch, Italian ryegrass) after corn at Arzua (1980-83)

Crop	Production (t/ha)
Rye	5.14
Oats + vetch	7.32
Italian ryegrass (6 month)	2.65
LSD (0.05)	0.72

Crop season	Production (t/ha)
1980-81	4.41
1981-82	6.42
1982-83	4.28
LSD (0.05)	0.69

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Rep	5	5.36	1.13	0.4054
Crop	2	196.08	103.15	0.0001
Rep*Crop	10	9.50	--	--
Crop season	2	51.73	25.32	0.0001
Crop season*Crop	4	84.71	20.73	0.0001
Error	30	30.65	--	--

In Arzua, the best crop in terms of production was oats and vetch and although its digestibility is lower than the Italian ryegrass, its much higher production makes the choice very clear. After vetch and oats, rye might be the better choice mainly because its greater and more uniform production compared with Italian ryegrass, although it was of poorer quality.

Forage rape The yield and chemical determinations are presented in Table 81. The average dry matter production was very low (1.17 t/ha). Forage rape produced in the field site at Arzua a very poor crop every year. In 1981, it was hard to find any plants that survived the winter; in 1982, some yield was obtained; but in 1983, due to the late seeding date in fall of 1982, the yields were again very low. The crop showed, however, a very high digestibility (78.60%).

Forage rape, or at least the variety used in this experiment, was not adequately cold resistant and also in order to survive the winter, the crop needed to be at a certain stage of growth before the cold weather. Almost every year the crop seemed to be damaged by winter. Another factor could be the soil quality at Arzua. The plant needs at least a pH above 6, and a normal quality soil (180). At Arzua, the soil pH was about 5.40 and the soil quality not very high, and this might have reduced the total growth of the plant but maybe more important the amount of growth before the winter which may have made it susceptible to winter damage. Other data support this hypothesis. In 1982, at the same planting date, another experiment with only Brassica species was conducted for the crop rotation experience, but it was on the very best soil of the farm. In this site, the yields of the forage rape at flowering were about 8 to 9 t/ha, much higher than the same variety at the crop rotation experiment.

This section can be summarized by saying that forage rape is not a crop adapted to poor soil and winter conditions, although it might be satisfactory at this type of site with high soil fertility situations.

Short- and long-term prairies The yield and chemical determinations for both types of mixtures are presented in Table 81. The average dry matter yields for the F_2 were 10.43 t/ha and for the F_6 9.31 t/ha. These figures are about 3 t/ha lower than at Mabegondo but the 1 t/ha difference between both mixtures was very similar to that at Mabegondo.

For the F_2 prairies, the values in Table 81 show very similar yields for the three years (9.22, 11.03 and 11.05 t/ha) and very little variation for the crude protein contents (13.17 to 16.79). However, the digestibility clearly decreased every year from 69.73 in 1981 to 60.07% in 1983. These changes were similar to those at Puebla and Mabegondo and reflect the changes in botanical composition (Table 83) with aging of the F_2 prairie. In Arzua, however, the change was not only due to the different proportion of the species of the initial mixture, but also to an increase in proportion of weeds which increased from 11.35% in 1981 to 36.28% in 1982. These values are much higher than for any of the previous two locations. The increased proportion of weeds, however, did not seem to affect very much the quality of the prairie compared with the other two locations, because the average crude protein acid

Table 83. Botanical composition of the prairies at Arzua (% of the total yield)

Crop	Cropping season	Grasses	Legumes	Weeds
Short duration (F_2)	1980-81	77.52	11.12	11.35
	1981-82	50.28	32.52	17.19
	1982-83	57.28	6.43	36.28
Short duration (F_2)				
Rotation prairies → corn	1980-81	81.46	3.64	14.88
Whole year production	1981-82	55.52	13.80	30.66
	1982-83	53.30	20.39	26.29
Long duration (F_6)	1980-81	75.15	7.61	17.23
	1981-82	48.13	7.88	43.97
	1982-83	29.85	12.11	58.03

detergent fiber, and digestibilities are very similar for all three locations. The protein contents were 16.26% at Mabegondo, 14.98% at Arzua and 13.43 at Puebla; the ADF values were 32.03, 32.25 and 32.73% at Mabegondo, Arzua and Puebla, respectively; and the digestibilities were 65.93%, 65.13% and 63.41% for the three locations. These coincidences could be, at least partially, due to the relatively colder spring and summer temperatures at Arzua, which helped the forage to have a relatively higher quality than in the other locations, because the plants did not grow as fast and were harvested at a relatively earlier stage of development. The possible higher quality of the seeded species might have overcome in some proportion the increased weed contents, although some papers reported a relatively high quality forage for certain weeds (228). Similar yields and qualities were found for the F_2 prairie of the prairies → corn rotation, although the interpretation may differ some because this rotation included a plot with an older prairie and a plot with a younger one than the sward of the F_2 prairie plot.

The prairie (F_2) of the plot that will have corn had, as at the other locations, a higher protein percentage and digestibility than the regular F_2 prairie plots because this plot reflects the spring growth of the sward which is of higher quality.

The long-term prairies (F_6) had poorer quality than those at Mabegondo, the crude protein was 14.10% at Arzua and 17.97% at Mabegondo, while the respective digestibilities were 67.86% and 70.71%. For the F_2 mixtures, the qualities did not differ very much between all three locations, but for the F_6, there were some measurable differences between Arzua and Mabegondo. The reason could be the large proportion of weeds (about 50%) in the mixture, at Arzua compared with Mabegondo. The crude protein and digestibilities of the F_6 crop decreased every year at Arzua but they do not seem to reflect the increased proportion of weeds, from 17.23% in 1981 to 58.03% in 1983.

The analysis of the prairies at Arzua can be summarized by saying that the F_2 type yielded fairly well, although less than at Mabegondo, because of weather and soil fertility differences. On the other hand, the F_6 type with perennial ryegrass-white clover mixture might not have been appropriate for these lower fertility soils because the swards were easily invaded with weeds, contributing to more than 50% of the total dry matter yield, which had an effect on the quality of the crop.

Analysis of the crop rotations The average yearly total dry matter yields, crude protein and digestibility and the ANOVA are presented in Table 84. A more detailed summary of the dry matter yields of the different rotations on each cropping season is given in Table 85. The analysis of variance shows significant differences among

Table 84. Annual average crop rotation dry matter yields, CP, IVDMD and ANOVA at Arzua (1981-83)

Crop rotation	DM (t/ha)	CP	IVDMD[a]
1. Corn	11.47	6.31	67.82
2. Corn → rye	15.44	7.04	66.89
3. Corn → oats + vetch	20.93	7.95	68.06
4. Corn → Italian ryegrass	12.75	6.83	70.06
5. Corn → Italian ryegrass → rape	9.77	8.52	68.05
6. Prairies → corn	11.73	11.47	66.13
7. Prairies (short duration)	11.04	14.98	65.13
8. Prairies (long duration)	10.22	14.10	67.86
LSD (0.05)	1.27		

Source of variation	d.f.	Sum of squares	F-value	Probabilty of a greater F
Blocks	5	6.53	0.55	0.7350
Rotation	7	1125.70	68.11	0.0001
Block*Rotation	35	82.75	--	--
Crop season	1	6.66	2.93	0.0945
Rotation*Crop season	7	100.77	6.34	0.0001
Error	40	90.88	--	--

[a]Several IVDMD values have been calculated from CP and ADF through regression equations.

Table 85. Dry matter yields of the cropping seasons and dry matter yields of the crop rotations at each cropping season at Arzua (1981-83)

Cropping season	DM (t/ha)
2. 1981-82	13.18
3. 1982-83	12.65

Crop rotation	Cropping season	DM (t/ha)
1. Corn	2	12.99
	3	9.95
2. Corn → rye	1	14.58
	2	16.29
3. Corn → oats + vetch	1	21.86
	2	20.00
4. Corn → Italian ryegrass	1	13.62
	2	11.87
5. Corn → Italian ryegrass → rape	1	11.13
	2	8.41
6. Prairies → corn	1	11.58
	2	11.89
7. Prairies (short duration)	1	11.03
	2	11.05
8. Prairies (long duration)	1	8.67
	2	11.78
	Mean	12.92

rotations and rotation*season. In general, there was an increase in dry matter production with a more intensive cropping system. This effect was also noticed in Mabegondo and Puebla. However, at Arzua the rotations which included rape and Italian ryegrass did not perform as well as at the previous two locations. The highest yields were produced by the double cropping rotations, corn → oats with vetch (20.93 t/ha), corn → rye (15.44 t/ha) and corn → Italian ryegrass (12.75 t/ha). After these three, all other sequences had similar yields, although the two-year corn → Italian ryegrass (12 month) → rape (9.77 t/ha) and the long-term mixture F_6 (10.22 t/ha) were the lowest yielding. At Arzua, there was not an intermediate step between double cropping and the prairies. On the other hand, the difference between the highest producing double cropping sequence and the F_2 prairies was about 6 t/ha at Mabegondo and Puebla, but at Arzua the difference was 10 t/ha. At Arzua, the highest yielding cropping sequences were the ones that included theoretical acid resistance and poor soil adapted crops like rye and oats with vetch. The rotation corn → oats + vetch with 20.93 t/ha produced the highest yield of any rotation in any of the three locations discussed, although its quality was a little lower than that of some rotations at Mabegondo. The rotations based on prairies at Arzua had higher protein contents than the ones with annual crops, because corn always had a poor protein average (6.319) compared with prairies (more than 14%).

The lowest average cropping season yields of the three locations was at Arzua, although in 1981-82 it yielded as much as Puebla (13.18

t/ha). This fact might indicate that on the average, Arzua was the poorest growing area.

A common result in the two previous locations which also was noticed at Arzua is that the yield of corn (11.47 t/ha) and the F_2 prairies (11.04 t/ha) were similar with higher digestibility for corn (67.82% vs. 65.13%), but lower crude protein (6.31% vs. 14.98%).

The average quality of forage at Arzua was less than at Mabegondo, but similar to that at Puebla. At Arzua, the double cropping systems which included crops adapted to poor soil conditions had much greater production than the other cropping sequences and the prairies.

Puenteareas

Before presenting the results found at Puenteareas, several comments need to be made regarding the special differences of the experiment at this location.

The data from Puenteareas are not really comparable with the results from the other locations for several reasons:

(1) Corn was irrigated during the summer but not in the other locations. However, in 1981 the irrigation was too late due to the lack of water in the reservoir, and the values obtained did not reflect the potential of the crop.

(2) Prairies were not irrigated. For this reason, it is not possible to make the same kind of comparisons of crop rotations-prairies done in the other locations.

(3) For logistical and climatological reasons, the fall seeding dates

at this location were much later (about 15 days) than at the others. In Galicia, the interval of time without rain between the harvest of corn and the seeding of the winter crops is normally very short. In some years, mainly 1981 and 1982, there was not time to seed all the experiments in one week without rain, and since this location was the most distant (about 3 hours of driving), it was sacrificed to the benefit of the others. For these reasons, the yields of the winter crops might not have reflected the potential of the area.

For the reasons given above, it does not seem reasonable to compare this location with the others. On the other hand, the information obtained from the experiment should be analyzed carefully in the sense that the yields of several crops might not reflect the true potential of the area, and they should be considered as lower than normal.

The final average annual dry matter yields for each rotation, the CP and ADF values and ANOVA are presented in Table 90. A summary of the dry matter yields for each cropping season is given in Table 91 and a detailed exposition of the yields and quality determinations of the crops throughout the duration of the experiment is shown in Tables 86 and 87.

<u>Analysis of crop yields and quality</u> No IVDMD were calculated for the crops at Puenteareas, and it was thought that the use of predicting equations for each one of the crops might produce a picture different from reality. It seemed more sound to use only the data found in the analysis.

Corn The dry matter yields, ear/total plant ratio, CP and ADF values are given in Table 86. The average dry matter yields varied much depending on the years. In 1981, the lack of irrigation reduced the yields to 8.55 t/ha, but increased to 15.05 t/ha in 1982 with two

Table 86. Average dry matter yield (t/ha) and percentages of CP and ADF of corn on different rotations and years at Puenteareas

Year	Rotation	D.M.	(Ear/total plant) x 100	CP	ADF	Density (plants/ha)
1981	Corn	8.16	34.29	7.96	29.88	
	C→rye	9.68	41.82	9.50	26.24	
	C→oats + vetch	9.66	39.02	8.37	28.60	
	C→It. ryegrass	8.48	39.93	7.49	28.59	
	C→It. rye → rape	7.25	39.40	9.62	25.95	
	Pastures→C	8.10	39.01	7.64	28.27	
Average		8.55	38.91	8.43	27.92	95,083
1982	Corn	14.94	53.58	5.78	22.69	
	C→rye	16.92	49.94	5.45	25.49	
	C→oats + vetch	14.85	51.85	5.56	24.17	
	C→It. ryegrass	14.69	54.39	5.93	23.64	
	C→It. rye → rape	14.38	53.55	6.11	22.97	
	Pastures → C	14.55	51.47	6.25	26.29	
Average		15.05	52.46	5.84	24.21	94,305
1983	Corn	19.01	58.33			
	C→rye	18.87	57.49			
	C→oats + vetch	19.42	58.49			
	C→It. ryegrass	18.88	55.93			
	C→It. rye → rape	18.38	57.99			
	Pastures→C	19.60	57.95			
Average		19.03	57.69			76,138
Average 1981-83						
	Corn	14.04	48.73			
	C→rye	15.16	49.75			
	C→oats + vetch	14.64	49.78			
	C→It. ryegrass	14.02	50.08			
	C→It. rye → rape	13.34	50.31			
	Pastures→C	14.08	49.47			
Average		14.21	49.68	7.13	20.06	88,500
ANOVA		n.s.				

irrigations. In 1983, like at Puebla de Brollon, there was a large summer rainfall, and with one irrigation the yields were 19.03 t/ha. These later values are in agreement with Moreno et al. (208) who reported yields between 17.83 and 22.93 t/ha of dry matter at Puenteareas in 1972. This location is situated in the southern part of Galicia where they have the hottest temperatures and the longest growing season for corn, and where the potential yields are among the highest of the region (206). However, this area is very dry during summer and irrigation must be provided for corn.

The results show an increasing ear/total plant ratio with increasing yields, increasing from 38.91% in 1981 to 57.69% in 1983. The ADF, on the other hand, was reduced from 27.92 in 1981 to 24.21% in 1982. These percentages are of the same magnitude as those at Puebla de Brollon but higher than those at Mabegondo, which may reflect the lowest ear/total plant proportion and the highest temperatures. The crude protein showed the normal increase for the drought stressed crops (8.43%) in 1981 compared with a more normal yield (5.84%) in 1982.

The ANOVA did not show significant differences for yield of corn in the different rotations. The rotations with the highest corn yield were corn → rye (15.16 t/ha) and corn → oats with vetch (14.64 t/ha).

In general, it is clear that when irrigation is provided, the yields of corn in this area can be very high according to Galician standards.

<u>Rye</u> The average yields of rye were 3.17 t/ha, with a 13.21% crude protein and 31.97% ADF (Table 87). This production was the lowest of the four locations and the most logical factor seems to

Table 87. Average dry matter yields (t/ha) and percentages of CP and ADF of the different crops for the cropping seasons at Puenteareas

Crop	Cropping season	DM	CP	ADF
Rye	1980-81	4.47	17.81	36.19
	1981-82	3.04	10.34	32.48
	1982-83	2.00	11.50	27.25
	Average	3.17	13.21	31.97
Oats + vetch	1980-81	4.74	18.55	34.75
	1981-82	8.23	8.58	36.74
	1982-83	3.17	11.40	28.04
	Average	5.38	12.84	33.17
It. ryegrass (6 months)	1980-81	4.88	13.85	25.77
	1981-82	4.64	7.84	27.73
	1982-83	2.45	9.56	24.76
	Average	3.99	10.41	26.09
It. ryegrass (12 months)	1980-81	9.16	14.22	32.00
	1981-82	7.17	8.30	30.21
	1982-83	8.96	8.93	33.21
	Average	8.43	10.48	31.80
Rape	1980-81	4.09	16.15	28.17
	1981-82	3.70	12.11	28.60
	1982-83	1.57	11.34	24.49
	Average	3.12	13.20	27.08
Prairies (short duration)				
Rot. Prairies → corn				
a. Whole year production (mean of two plots)	1980-81	11.64	15.81	31.83
	1981-82	9.48	12.09	31.89
	1982-83	12.65	14.56	34.87
	Average	11.26	14.15	32.86
b. From fall until corn seeding of the plot that will carry corn	1980-81	5.00	18.44	25.45
	1981-82	3.89	17.16	28.26
	1982-83	6.48	15.03	32.42
	Average	5.12	16.87	28.71
Prairies (short duration)	1980-81	11.86	15.82	31.53
	1981-82	10.63	16.80	30.86
	1982-83	13.13	13.95	35.70
	Average	11.87	15.52	32.69
Prairies (long duration)	1980-81	9.44	19.37	33.12
	1981-82	9.77	17.49	32.54
	1982-83	13.49	11.98	33.34
	Average	10.90	16.28	33.00

the late fall seeding (about three weeks) compared with the other experiments. Harvesting time was similar at all locations. The variety of rye used was a postrate type and did not compete well with weeds at Puenteareas. The protein content (13.21%) was only higher than the crop at Arzua (11.37%) and the ADF percentage was similar to those at Mabegondo and Puebla. The much lower yields in 1983 were mainly due to the very late seeding in 1982 (November 2) because of the persistent rainfall. In general, rye at Puenteareas was a poor crop.

Oats with vetch The average dry matter yields (5.38 t/ha), crude protein (12.84%) and ADF (33.17%) are presented in Table 87. The annual yields varied from 8.23 t/ha in 1982 to a low of 3.17 t/ha in 1983 because of the late fall seeding. The lowest quality was found with the highest dry matter production. Compared with the other locations, the crop did fairly well, with production similar to that at Mabegondo (5.22 t/ha) and higher than at Puebla (4.88 t/ha) but lower than at Arzua (7.31 t/ha). The quality, however, was almost the lowest but similar to that at Arzua.

As a summary, the production was good, but the quality was low.

Italian ryegrass The results found at Puenteareas show an average dry matter production of 3.99 t/ha for the 6 months crop and 8.43 t/ha for the 12 month crop. The protein percentage was very similar for both crops (10.41-10.48%) and the ADF, lower for the 6 month crop (26.09 vs. 31.80%) (Table 87).

The production for the 6 months crop (3.99 t/ha) was very similar to that at Puebla (3.96 t/ha) and Mabegondo (4.29 t/ha), even with the later seeding time at Puenteareas. The quality of the crop, however, was lower because even if the harvesting times were similar at these three locations, the spring temperatures are normally higher at Puenteareas and the crop was at a later maturity stage. The protein percentages were 10.41% at Puenteareas, 13.48% at Mabegondo and 16.07% at Puebla, and the mean ADF was higher at Puenteareas.

The Italian ryegrass (12 month) yields (8.43 t/ha) were almost the lowest of all four locations, only higher than at Arzua (7.89 t/ha). The reason, as in Puebla de Brollon, was the hot-dry summer of the area, which almost totally reduced the growth of the crop during the summer. The yield difference between the 6 and 12 months crop was only a little more than 4 t/ha and most of this production was provided by the June harvest. For the 12 month crop, the quality at Puenteareas was the lowest of all locations with only 10.48% crude protein. The ADF (31.80%) was slightly lower than at Puebla (35.15%).

The data presented show that, although the crop has potential when double cropped with corn, the hot and dry end of spring and summer conditions are not very appropriate for a whole year crop of Italian ryegrass.

<u>Comparison of the winter crops after corn (rye, oats with vetch and Italian ryegrass, 6 months)</u> The analysis of variance, presented in Table 88, shows significant differences bewteen crops and cropping seasons. Oats with vetch (5.38 t/ha) was the highest yielding crop, while Italian ryegrass produced 3.99 t/ha and rye 3.17 t/ha. On the other hand, the 1982-83 winter season, because of late seeding,

Table 88. Analysis of variance of the comparison of the dry matter production of the winter crops (rye, oats + vetch, Italian ryegrass) after corn at Puenteareas (1980-83)

Crop	Production (t/ha)
Rye	3.17
Oats + vetch	5.39
Italian ryegrass	3.99
LSD (0.05)	0.67

Crop season	Production (t/ha)
1980-81	4.70
1981-82	5.31
1982-83	2.54
LSD (0.05)	0.66

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Rep	5	5.39	1.30	0.3362
Crop	2	44.75	27.03	0.0001
Rep*Crop	10	8.28	--	--
Crop season	2	76.01	40.66	0.0001
Crop season*Crop	4	44.71	11.96	0.0001
Error	30	28.04	--	--

produced much less (2.54 t/ha) than the other two (4.70 and 5.31 t/ha).

Of these three crops, oats with vetch usually produced the highest yields with similar or higher protein contents, although with higher ADF than Italian ryegrass, and oats with vetch seems the most appropriate crop. However, if high digestibility (or low ADF) is necessary, Italian ryegrass should be considered.

Forage rape The average dry matter yields (3.12 t/ha), crude protein (13.20%) and ADF (27.08) are presented in Table 87. The yields were not very high. As it was seen at Arzua, the crop was sensitive to the winter, and it appeared as though it needs a certain stage of growth in order to tolerate the season. At Puenteareas, the seeding dates were late compared with the other locations and maybe too late for this crop. In 1982, the seeding dates were very late (November 2) and the crop did very poorly, only 1.27 t/ha. However, the quality of the crop was very similar at all four locations, and at Puenteareas generally better than any of the other winter crops. Forage rape had a little higher ADF than Italian ryegrass (6 months) (27.08 vs. 26.09%).

Forage rape could be a desirable crop at this location if appropriate seeding times and management are provided.

Short- and long-term prairies Dry matter yields, crude protein and ADF percentages for both types of mixtures are presented in Table 87. The F_2 (short-term prairies) yields (11.87 t/ha) were about 1 t/ha higher than the F_6 (long duration prairies) (10.90 t/ha). These differences were similar to those at other locations, except for Puebla, where the comparison was not possible. On the other hand, the average crude protein was a little higher for the F_6 (16.28%) than for the F_2 (15.52%). However, the ADF which normally is lower for the F_6 than for the F_2 showed the opposite (33.00% for the F_6 and 32.69% for the F_2).

It is clear that during the 1982-83 cropping season, the dry matter yields of the F_6 were much greater compared with the other two years (13.49 vs. 9.55 t/ha), and that the crude protein was much reduced in that year (11.98% vs. about 18%), while the ADF were similar. The most reliable explanation seems to be due to the herbicide treatment in the spring of 1983. Table 89 shows how the botanical composition of the

Table 89. Botanical composition of the prairies at Puenteareas (% of the total yield)

Crop	Cropping season	Grasses	Legumes	Weeds
Short duration (F_2)	1980-81	73.94	15.49	10.59
	1981-82	38.09	40.03	21.88
	1982-83	62.36	23.51	14.13
Short duration (F_2)				
Rotation Prairies → corn	1980-81	75.87	13.84	10.29
Whole year production	1981-82	65.81	19.12	15.06
	1982-83	51.62	34.04	14.31
Long duration (F_6)	1980-81	49.84	33.40	16.75
	1981-82	29.31	27.42	43.26
	1982-83	71.90	8.90	19.18

mixtures changed every year and how during the 1981-82 cropping season the percentage of weeds, mostly Rumex ssp. made about 43.26% of the total yield.

A herbicide treatment with Asulam was given and the botanical analysis shows that it was effective in reducing the proportion of weeds. In addition, it appeared that some Italian ryegrass seeds were dormant or came from other plots and invaded some plots of the perennial ryegrass-white clover prairies, thus raising the yields, and lowering the quality. A different explanation is that the rainy summer of 1983 increased the production of both type prairies.

The production of the long-term prairies (F_6) (10.90 t/ha) was lower in yield but similar in protein contents (16.28%) and ADF (33.00%) to the same mixture at Mabegondo. However, compared with Arzua the yield, protein contents and also the ADF were higher. According to these results, Mabegondo was the best location for the long-term swards, and Puenteareas was a little better than Arzua.

For the short duration mixtures, the yields in Puenteareas were about 2 t/ha lower than at Mabegondo but higher than at the other two locations. The crude protein and ADF were respectively lower and higher than at Mabegondo, but higher and equal at the other two locations. The prairies of the plots that will have corn on spring had, as usual, higher quality than the rest of the F_2 plots, but as it is known, these plots reflect the spring production. The yield differences between the short duration mixture and the plots of F_2 that will have corn in the spring at Puenteareas were about 6.7 t/ha, at Mabegondo 9.37 t/ha, at Puebla 6 t/ha and at Arzua about 7.81 t/ha. These figures show that at the locations with higher summer temperatures and lower rainfall, the growth of the prairies was reduced more than at Mabegondo and Arzua.

The comparisons between F_2 prairie and corn are not of interest because the corn was irrigated. However, in 1981 when the corn was watered too late in the season (after pollination), the yields of the F_2 (11.86 t/ha) were higher than those of corn (8.55 t/ha).

Another subject for discussion with the F_2 prairies is the decrease in quality with age which was observed at all locations including Puenteareas. The average crude protein decreased from about 16% to 13.95% in 1983 and the ADF increased from 31.53% in 1981 and 30.86% in 1982 to 35.70% in 1983.

As a summary, both types of prairies had a fair growth during the spring but during the summer little growth occurred. This might have had a more detrimental effect on the F_6 mixture because the plots were more invaded with weeds and at Puenteareas the F_6 did not have the superior quality forage that the F_2 showed at the other locations.

Analysis of the crop rotations The average total dry matter yields, crude protein and acid detergent fiber and the ANOVA are presented in Table 90. A more detailed summary of the dry matter yields of the different rotations for each cropping season is given in Table 91. As it was exposed at the beginning of the Puenteareas section, a true comparison between prairies and several crop rotations cannot be made because of the different growing conditions of corn which was irrigated. In these comparisons, the prairies and the Italian ryegrass were adversely affected because the lack of water greatly reduced their summer growth. However, Table 90 shows that the three effects found at the other locations also occurred at Puenteareas. First, the typical yield increase with increasing cropping intensity (although here corn was irrigated). Two, the general decrease in protein contents when the proportion of corn in the rotation increased. Three, the normally higher quality of the rotations with corn compared with the prairies.

It is the opinion of the author that without all the agronomic and

Table 90. Crop rotation dry matter yields, crude protein and acid detergent fiber percentages and ANOVA at Puenteareas (1980-83)

Crop rotation	DM (t/ha)	CP	ADF
1. Corn	14.04	7.13	26.06
2. Corn → rye	18.34	8.32	27.05
3. Corn → oats + vetch	20.02	8.89	27.64
4. Corn → Italian ryegrass	18.01	7.99	26.05
5. Corn → Italian ryegrass → rape	12.45	9.12	28.13
6. Prairies → corn	13.91	12.17	31.05
7. Prairies (short duration)	11.88	15.52	32.69
8. Prairies (long duration)	10.90	16.28	33.00
LSD (0.05)	2.54		

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Blocks	5	94.00	1.33	0.2737
Rotation	7	1451.40	14.69	0.0001
Blocks*Rotation	35	494.11	--	--
Crop season	2	879.59	113.68	0.0001
Rotation*Crop season	14	354.33	6.54	0.0001
Error	80	309.49	--	--

Table 91. Dry matter yields of the cropping seasons and dry matter yields of the crop rotations at each cropping season at Puenteareas (1980-83)

Cropping season	DM (t/ha)
1. 1980-81	11.73
2. 1981-82	15.36
3. 1982-83	17.74
LSD (0.05)	0.80

Crop rotation	Cropping season	DM (t/ha)
1. Corn	1	8.16
	2	14.94
	3	19.01
2. Corn → rye	1	14.16
	2	19.97
	3	20.28
3. Corn → oats + vetch	1	14.40
	2	23.09
	3	22.59
4. Corn → Italian ryegrass	1	13.36
	2	19.37
	3	21.33
5. Corn → Italian ryegrass → rape	1	10.25
	2	12.63
	3	14.45
6. Prairies → corn	1	12.21
	2	12.47
	3	17.06
7. Prairies (short duration)	1	11.86
	2	10.63
	3	13.13
8. Prairies (long duration)	1	9.49
	2	9.77
	3	13.49
	Mean	14.94

logistic problems exposed in the introduction of this section, the average total yields of corn and winter crops would have been higher, maybe from 4 to 7 t/ha. On the other side, the irrigation of the prairies during the summer also would have increased greatly their annual production.

Soil fertility aspects of the crop rotation experiment

In order to know the possible effects of the crop rotations and their fertilization on the soil fertility, soil samples of each plot were taken during the spring of 1983 before corn. The results for each location are presented in Tables 92, 93, 94 and 95 and were analyzed for possible differences among treatments and compared with the initial analysis of the samples taken in April or November of 1980.

Mabegondo The average initial (1980) soil determinations were the following: pH 5.56, organic matter 3.15%, extractable phosphorus 44.80 ppm, and extractable potassium 294.5 ppm. The final (1983) determinations are presented in Table 92. The ANOVA showed a significant difference among rotations for the pH and extractable K.

For soil pH, the samples from the rotation of corn → oats with vetch (rotation 3) had the highest pH (6.12). As it was commented in previous sections, 1000 kg/ha of lime was applied every year before seeding the oats, and this is the most likely reason for the higher soil pH compared with other rotations. It is also interesting to notice that the pH of Treatment 8 (long-term prairies) increased every year; the most recently seeded prairie had the higher pH. The activity of the

Table 92. Soil fertility determinations at Mabegondo

Rotation	pH	OM (%)	P (ppm)	K (ppm)	Al^{+++} (meq/ 100 gr)	CEC	$\frac{Al^{+++}}{CEC}$
1.	5.88	3.13	56.5	380.3	0.25	7.73	0.03
2.	5.85	2.89	53.0	342.6	0.29	6.38	0.05
3.	6.12	2.77	57.66	306.1	0.25	9.48	0.03
4.	5.80	2.71	62.16	297.8	0.27	6.74	0.05
5.	5.83	2.92	61.33	332.95	0.34	7.15	0.05
6. Corn in 1981	5.76	2.59	58.16	245.00	0.31	7.69	0.04
Corn in 1982	5.82	2.68	61.33	214.8	0.37	6.52	0.06
Corn in 1983	5.57	2.58	65.83	206.6	0.40	7.35	0.07
7.	5.60	2.53	57.50	258.0	0.36	7.30	0.04
8. Seeded spring 1980	5.37	2.62	45.33	255.5	0.37	7.05	0.06
Fall 1980	5.67	2.48	47.16	263.1	0.28	7.68	0.04
Fall 1981	5.88	2.53	44.16	278.8	0.21	8.05	0.04
Fall 1982	5.95	2.51	43.16	237.8	0.19	7.19	0.03
Mean	5.78	2.70	54.86	278.4	0.30	7.41	0.04
ANOVA	S-1%	NS	NS	S-1%	NS	--	NS
LSD	0.28	--	--	87.1	--	--	--

lime applied previously to the seeding of the prairies decreased with time and the most recent application had more effect on soil pH.

The more interesting aspects of the soil test may be the changes in levels of phosphorus and potassium. The ANOVA did not show significant differences among treatments for the phosphorus level, but it was significant for potassium.

The soil phosphorus contents of the rotations and prairies show that the crop rotations and the short-term prairies with corn had values between 53.0 and 65.83 ppm of extractable phosphorus. However, the long-term prairies only averaged between 43.16 and 47.16 ppm, which is similar to the values of the initial soil test (44.80 ppm). The annual applications of superphosphate to long-term prairies maintained phosphorus level of the soil, whereas for the crop rotations and the prairies with corn, the level of soil phosphorus increased. The most reasonable explanation is that these rotations received too much phosphorus for their needs and maybe the levels recommended (143) should be reduced when working in areas similar to Mabegondo with these Galician cropping systems.

The soil potassium levels for the annual and biannual crop rotations ranged between 297.8 and 380.3 ppm. For the prairies with corn, the values were between 206.6 and 258 ppm and for the long-term prairies between 237.8 and 278.8 ppm. The initial soil test values were about 294.5 ppm. In this case, it looks like the fertilization levels of the rotations with annual crops have increased the soil potassium values while the fertilization for both types of prairies has maintained or decreased the soil levels. In the case of potassium, it also appears that the levels recommended for some areas could be somewhat reduced for Mabegondo when dealing with crop sequences based on annual crops.

The general summary for Mabegondo is that the levels of phosphorus and potassium applied to the rotations based on annual crops need further research because the recommended rates might be excessive for the conditions of the area.

Puebla de Brollon The average initial (1980) soil determinations were pH 6.00, organic matter 3.24%, extractable phosphorus 46.51 ppm, and extractable potassium 145.86 ppm. These levels were similar to those at Mabegondo, except for the soil pH, which was higher at

Table 93. Soil fertility determinations at Puebla de Brollon

Rotation	pH	OM (%)	P (ppm)	K (ppm)	Al^{+++} (meq/ 100 gr)	CEC	$\frac{Al^{+++}}{CEC}$
1.	6.15	3.18	97.50	148.5	0.34	8.80	0.04
2.	6.15	3.29	92.33	177.0	0.37	10.18	0.04
3.	6.57	3.07	84.66	123.1	0.21	10.96	0.02
4.	6.26	3.04	91.00	162.3	0.28	9.26	0.03
5.	6.18	3.41	82.49	156.2	0.38	9.56	0.04
6. Corn in 1981	6.44	3.26	77.50	161.6	0.25	12.19	0.02
Corn in 1982	6.77	3.34	85.00	182.5	0.23	13.23	0.02
Corn in 1983	6.38	3.53	80.16	150.3	0.35	11.34	0.03
7.	6.42	3.46	83.50	136.1	0.40	10.36	0.04
8. Seeded Spring 1980	6.42	3.46	99.0	132.3	0.34	11.55	0.03
Mean	6.37	3.31	87.31	152.9	0.32	10.74	0.03
ANOVA	S-1%	NS	NS	NS	NS	--	S-5%
LSD	0.14	--	--	--	--	--	0.017

Puebla and the level of potassium was about 150 ppm lower. The final (1983) soil determinations are presented in Table 93. Table 93 shows significant differences for soil pH among rotations, and that the highest values were given by the rotations that received lime such as corn→oats with vetch (6.57) (treatment 3) or prairies→corn (treatments 6 and 7) (6.42-6.77).

Compared with the initial soil analysis, the levels of phosphorus found three years later were almost doubled. This could indicate that the fertilization was excessive. The total yields at Puebla were normally inferior to those at Mabegondo and both locations received the same levels of utilization. For the potassium levels, however, the final average (152.9 ppm) was very similar to the initial level (145.86 ppm).

As a general summary for Puebla, the levels of phosphorus probably were excessive. The plots receiving lime dressings showed higher final pH values.

Arzua The average initial (1980) soil determinations were pH 5.40, organic matter 7.86%, extractable phosphorus 6.46 ppm, and extractable potassium 74.20 ppm. These values reflect the lower soil fertility of this location compared with Mabegondo and Puebla de Brollon (lower pH and lower phosphorus and potassium content, although higher organic matter contents).

The results of the final determinations are presented in Table 94. The ANOVA showed significant differences for all the factors analyzed.

Table 94. Soil fertility determinations at Arzua

Rotation	pH	OM (%)	P (ppm)	K (ppm)	Al^{+++} (meq/ 100 gr)	CEC	$\frac{Al^{+++}}{CEC}$
1.	5.21	7.42	20.00	204.0	1.17	4.42	0.29
2.	5.18	6.98	28.50	138.8	1.35	3.76	0.36
3.	5.44	7.03	25.00	159.6	0.57	5.54	0.11
4.	4.97	7.16	33.33	185.6	1.31	3.88	0.34
5.	5.23	6.82	26.25	209.5	1.15	4.36	0.27
6. Corn in 1981	5.71	9.06	24.66	155.0	0.45	7.44	0.06
Corn in 1982	5.62	8.15	22.00	224.0	0.48	6.43	0.08
Corn in 1983	5.39	9.02	17.50	176.0	0.82	6.63	0.13
7.	5.32	8.45	17.50	149.8	0.71	4.93	0.15
8. Seeded Spring 1980	5.32	8.77	20.16	191.0	0.69	5.24	0.13
Fall 1980	5.62	8.07	12.83	148.6	0.37	5.88	0.06
Fall 1981	5.71	8.79	12.16	199.3	0.32	6.97	0.05
Fall 1982	5.73	8.76	5.33	192.8	0.47	7.30	0.07
Mean	5.40	7.95	20.40	179.5	0.79	5.59	0.17
ANOVA	S-1%	S-1%	S-1%	S-1%	S-1%	--	S-1%
LSD	0.17	0.72	20.9	51.5	0.34	--	0.08

As at Mabegondo, the pH was higher for the plots receiving annual applications of lime. Among the annual crop rotations, the corn → oats with vetch sequence had a high pH (5.44), and some prairie treatments showed the highest values (5.73).

Another similarity with Mabegondo is the fact that the pH of the long term mixtures (treatment 8) increased with later seeding years, that is, the plots most recently seeded had higher pH values. The total average (5.40), however, was identical to the initial soil tests. The same was true for the organic matter determinations.

The final average determinations for phosphorus and potassium were 20.40 and 179.5 ppm, respectively. These figures are higher than the initial values (6.46 and 74.20 ppm for phosphorus and potassium, respectively), showing an increase in the fertility of the soil. The annual and biannual crop sequences (treatments 1 to 5) showed higher phosphorus values (20 to 33.33 ppm) than the prairies → corn (treatment 6) (17.5 to 24.66 ppm) and the permanent pastures (treatment 8) (5.33 to 20.16 ppm). On the average, the treatments that received greater applications of supherphosphate had higher phosphorus extractions. The most interesting point is the analysis of the long-term prairies, where a new plot was seeded every year. Table 94 shows that the oldest plot of the mixture, which was seeded in the spring of 1980, had a higher phosphorus extraction (20.16 ppm) than the plots seeded in the falls of 1980 and 1981 (12.83 and 12.16 ppm, respectively) and much higher than the plot seeded in the fall of 1982 (5.33 ppm). The extractable phosphorus increased every year with every additional top dressing of fertilization. The value for the long-term mixture seeded in the fall of 1983 (5.33 ppm) is similar to the 6.46 ppm found in the initial soil analysis. An explanation could be the decrease of P availability because of the amounts of lime (305).

The extractable potassium values were also much higher than the initial ones, and although the ANOVA showed significant differences among treatments, it is difficult to see any clear trend. It can be noticed that the two highest yielding crop rotations, corn → rye (treatment 2) and corn → oats with vetch (treatment 3), are among the treatments that had lower potassium extractions.

An interesting point at Arzua is that most of the treatments had ratios of Al^{+++}/CEC higher than 10%, indicating possible detrimental effects of Al^{+++} (305). Only the crop sequences that received lime had values below 10%.

As a summary for Arzua, this location had the lowest soil fertility of the three locations presented so far. The low pH and the relatively high Al^{+++}/CEC values reflect possible soil acidity problems. On the other hand, the final extractable phosphorus and potassium showed higher values than the initial determinations. In a location like Arzua, an increase in the soil fertility may be advisable; however, the values seem to indicate that the dosages of fertilizers used were higher than the needs.

<u>Puenteareas</u> The average initial (1980) soil determinations were pH 5.66, organic matter 5.16%, extractable phosphorus 46.83 ppm, and extractable potassium 157.31 ppm. These values are similar to the

presented for Puebla de Brollon except the pH of the later location was higher (6.00).

The results of the final determinations are presented in Table 95. The ANOVA showed significant differences in pH, extractable P, K and

Table 95. Soil fertility determinations at Puenteareas

Rotation	pH	OM (%)	P (ppm)	K (ppm)	Al^{+++} (meq/ 100 gr)	CEC	$\frac{Al^{+++}}{CEC}$
1.	5.46	5.54	71.83	221.5	0.63	6.11	0.11
2.	5.63	5.41	86.50	201.6	0.46	7.19	0.08
3.	5.75	5.50	60.00	182.5	0.34	7.26	0.05
4.	5.57	5.32	71.00	160.1	0.48	6.72	0.08
5.	5.53	5.99	72.08	17.32	0.89	6.21	0.15
6. Corn in 1981	5.67	5.81	53.33	177.1	0.43	7.19	0.06
Corn in 1982	6.02	5.05	52.83	161.7	0.27	8.90	0.03
7.	5.51	5.34	52.00	191.6	0.54	7.67	0.08
8. Seeded Fall 1980	5.58	5.89	54.50	205.3	0.32	8.05	0.04
Fall 1981	6.00	5.89	50.66	262.8	0.16	11.12	0.02
Fall 1982	6.07	5.90	42.00	172.0	0.17	9.56	0.02
Mean	5.68	5.59	60.61	191.75	0.46	7.81	0.06
ANOVA	S-1%	NS	S-1%	S-5%	S-1%	--	S-1%
LSD	0.22	--	20.1	28.3	0.32	--	0.06

Al^{+++} and on the ratio Al^{+++}/CEC. Although the analysis of variance shows significant differences for the pH of the different rotations, it is very difficult to find any trend. As at the other locations, the rotation of oats with vetch (treatment 3) usually had a higher pH than the annual or biannual sequences (treatments 1 to 5). On the other hand, the prairies also generally had a higher pH. The long-term mixture (treatment 8) also had, as at Mabegondo and Arzua, a higher pH for the more recently seeded plots. The average for all the treatments, however, was similar at the end of the experiment (5.68) to the value at the beginning (5.66).

The ANOVA for the extractable phosphorus showed a significant difference among treatments. In general, the annual and biannual sequences had higher levels (60.00-86.50 ppm) than either the pastures → corn (52.00-53.33 ppm) or the long-term pastures (52.00-53.33 ppm). As at Arzua, the treatments that received more applications of superphosphate had higher phosphorus extractions. For the long-term pastures, the older plots had higher levels than the more recent ones, as it was found at Arzua. This fact could be due to the more phosphorus received by the plots, or by the decrease in P availability due to the lime applications. On the average, the extractions made at the end of the experiment (60.61 ppm) were higher than the initial ones (46.83 ppm).

The ANOVA for the potassium also shows significant differences among treatments, but no clear trend was observed. However, the final determinations were higher (191.75 ppm) than the initial (157.31 ppm). The ratio of Al^{+++}/CEC, as expected, showed lower values for the treatments that received lime.

In general, the conclusion is similar to those for the other locations, which is that the fertilization of the crop sequences increased the levels of extractable phosphorus and potassium.

General discussion

The level of intensification of the cropping systems is a common issue discussed around the world and can be evaluated from many different points of view (4, 7, 42, 171, 236, 256, 306). In certain areas of the planet, the main concern is the production of enough food to feed their people (7). In a developed area, these basic needs are normally satisfied and the intensification of agricultural production is related to increased farm output, to maximized biomass, to the value of reduced soil erosion, and most of the time to economic aspects.

In some areas of western Europe, forage intensification is the answer where land is the limiting production factor (177, 215, 247, 257). This is normally the case in Galicia, where in the last centuries there has been a population pressure that has led to very small farm size, and therefore forcing the farmer to the adaptation of intensive cropping systems. This trend with some variation still remains up to the present (22, 176). Presently, many farmers are oriented to the production of milk and beef based on prairies and on annual crops. However, no comparison of the most common cropping systems has been done, and this was the main objective of this group of experiments. The fundamental objective of this research was to compare forage productions of the most common crop rotations and prairies. These kinds of contrasts are only valid on a cropland situation where both types of crops can grow adequately. The data which were obtained will provide basic information for the productivity and economic analysis of the Galician cropping systems. Several main aspects can be discussed from the analysis of the results.

<u>Comparative production of crop rotations and pastures</u> The results found in each location have been presented in Tables 72, 78, 84 and 90. The data show a very similar trend at all locations. It is

very clear that there is an increase in forage production with a more intensive cropping system. In every location, the double cropping systems corn → rye, corn → oats with vetch and corn → Italian ryegrass gave the highest yields. At Mabegondo and Arzua, the rotation corn → oats with vetch yielded the most, with 19.70 and 20.93 t/ha, respectively, while at Puebla de Brollon corn → rye and corn → Italian ryegrass produced similarly 16.08 and 16.71 t/ha, respectively. The next highest level of production is represented by the two cropping sequences of corn → Italian ryegrass → rape with three crops in two years and by prairies (2 years) → corn. The yields of these rotations were respectively 16.57 and 16.06 t/ha at Mabegondo, 13.64 and 12.73 t/ha at Puebla de Brollon and 9.77 and 11.73 t/ha at Arzua. The least productive cropping system, except at Arzua, is represented by the prairies and by monocropped corn. Their yields were between 12.15 and 13.76 t/ha at Mabegondo, between 10.53 and 11.16 t/ha at Puebla de Brollon, and between 10.22 and 11.47 t/ha at Arzua. An interesting point is that in all locations the dry matter yields of the short-term prairies and corn were similar, although the quality of the two types of production differed. Another interesting point is the fact that both types of prairies, short and long duration, gave similar yields although the quality was normally higher in the long-term prairies.

At Mabegondo, the percentage increase in dry matter production of the most productive double cropping system compared to corn or short-term prairies was about 43%, while at Puebla it was around 49% and at Arzua about 82%. The increase of production with the double cropping systems is clear and have also been reported in other countries. The area with forage systems most similar to those of Galicia is France where in the northwestern part the main sequence is corn → Italian ryegrass. Yields vary with locations but in general they obtain about 10-13 t/ha for the corn plus 3-5 t/ha for the Italian ryegrass (256, 257). These intensive cropping systems, however, are becoming more criticized because they are higher labor demanding and because of their climatic conditions the intervals between the harvest of one crop and the seeding of the next are very short and many times the field work has to be done under adverse conditions. This also can be a problem in Galicia, but the smaller farms and the somewhat different weather pattern is helpful.

In Belgium, the corn → rye or corn → Italian ryegrass produced about 13-14 t/ha, while the corn monocropped 11-11.5 t/ha (247, 313). In the U.S.A., Murdock and Wells (218) in Kentucky found that double cropping corn with oats or barley produced 26% more dry matter for silage (20.3 t/ha) than a single crop of corn (15.78 t/ha). In Minnesota, Crookston et al. (57) were interested in biomass production, and they found that double cropping corn and rye produced 25.9 t/ha, while corn monocropped 18.8 t/ha. Fuehring (95) in New Mexico compared corn alone, corn double cropped with barley and a three crop in two year systems. The productions were 15.23 t/ha for corn alone, 17.13 t/ha for a three crops in two years system and 26.62 t/ha for the double cropping system. In Iowa, Helsel and Wedin (123) reported that corn or sorghum x sudangrass double cropped with rye produced 3-4 t/ha more than the main crops alone. Fewer reports have been published about production of permanent natures and rotations of crops and pastures. In general, they show (7, 57, 95, 123, 218, 247, 256) a yield increase with a more intensive system. The data found in this present experiment clearly showed that the intensification increased the forage yields.

A question that is asked when discussing the yields of the crop rotations is the following: What would have happened if the less intensive systems would have received the same amount of fertilizer as the more intensive? This question mainly refers to the N fertilizer used when comparing the double cropping systems with pastures. It is clear that the production by the pastures would have increased, but their botanical composition would also have changed and instead of having a mixture of grasses and legumes, it would have ended being mainly a grass pasture. On the other hand, several papers have shown that the total yields did not change very much (12, 20, 118, 137, 204, 249) because until the legume disappeared, it decreased the efficiency of N fertilizer use. In general, the question is complex, but with double cropping systems, the summer crop, corn, can take advantage of the climate much better than the prairies which have most of their growth in spring, while the winter crop yields at least as much as the prairies during the period winter to spring. Other types of economic and quality considerations can be made, but they will be discussed later.

Location differences   The results showed production differences among locations. The average production for Mabegondo, Puebla de

Brollon and Arzua and the ANOVA are presented in Table 96. For Mabegondo, the average yield of all the treatments but the long-term

Table 96. Overall production comparison between the different locations and rotations (long-term prairies not included)

Location	Production (t/ha)
Mabegondo	16.42
Puebla de Brollon	13.71
Arzua	13.32
LSD (0.05)	2.03

Rotations	Production (t/ha)
1. Corn	12.03
2. Corn → rye	16.60
3. Corn → oats + vetch	18.58
4. Corn → Italian ryegrass	15.53
5. Corn → Italian ryegrass → rape	13.38
6. Prairies → corn	13.51
7. Prairies (short)	11.77
LSD (0.05)	3.10

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Locations	2	240.04	6.55	0.0119
Rotations	6	681.99	6.21	0.0037
Location*Rotations	12	219.77	--	--
Rep (Locations)	15	75.37	1.19	0.2944
Error	90	380.25	--	--

prairies is 16.42 t/ha, for Puebla de Brollon 13.71 t/ha and 13.32 t/ha for Arzua. These differences in total average yield production and the analysis of each particular crop are the estimate of the potential production of the area.

The climatology and the soil fertility are two of the main factors that determine production. Under a rainfed situation like in this experiment, Mabegondo is the most productive area, while Puebla de Brollon and Arzua yielded similarly. The locations have very different climatology and soil fertility. At Puebla de Brollon, the most limiting factor seems to be the hot dry summer weather that restricted the summer growth due to the lack of water, and the same is true for Puenteareas. At Arzua, on the other hand, the yields might be most limited by low soil fertility and cooler weather that shortens the growing season. Mabegondo is intermediate, mainly because it is near the seashore and has a milder climate than the other sites. Notwithstanding the different production potentials, the relative position of the cropping systems was similar and the most intensive sequences always outyielded the less intensive. The relative positions and the production potential of the locations could have changed much with irrigation. It was shown at Puenteareas that when the irrigation was sufficient, the dry matter yields of corn increased from 8 to 19 t/ha, and similar yields have been reported for Puebla (208, 243) also with irrigation. At Mabegondo and Arzua, no irrigation data are available, but because of their milder temperatures, the proportional increase in production would not have been as great as at Puebla de Brollon and Puenteareas.

Corn as a factor of intensity Corn is really the key crop in the intensity of the rotations, not only for the aspect of its higher yield production in short period of time, but because it allows double cropping, and this extra production by the winter crop is what makes the difference when comparing prairies with two crops in a year system. In the double cropping systems, at Mabegondo corn represented from 68 to 78.52% of the total yield, at Puebla de Brollon from 66 to 74% and at Arzua from 54 to 89%. This factor of intensity is the main reason why corn has been so successful in the forage production systems of south-central Europe (168, 257, 312, 343). In certain areas of France, the introduction of corn has been viewed as an agricultural revolution which transformed cropping systems (87). In New Zealand agriculture, maize silage is used to intensify dairy production and modify the seasonality of the prairie systems (158, 300).

However, the yield of corn in some of these areas has been very variable and this is often mentioned as a major handicap of the crop (257, 279). Some English data reported coefficients of variation of about 20%, whereas for ryegrass they were 17% (279). In the northwest coast of France, the variations reported varied from 50 to 140% of the mean yield in a 6-year period; however, the summer production of the grasses, mainly ryegrasses, was higher. In this present research, the yields at Mabegondo varied from 92 to 105%, at Puebla from 77 to 138% and at Arzua from 97 to 103%. In this dissertation, corn was only seeded three years, but the average variations look smaller. The most probable reason could be that Galicia, or at least the sites of the experiment, is better suited for corn and for double cropping systems than most of these higher latitude areas of mid-central Europe.

The delay in seeding is a common cause of poor performance in corn and can be a problem in double cropping systems if the previous crop is not harvested in time (256). However, when corn was seeded at the proper time, no effect of the precedent ryegrass crop was found (256), and the same was true in the experimental part of this dissertation.

The yields of corn varied depending on the location, but this should be expected because the summer climatological conditions were different. For this reason, the average yields at Puebla de Brollon and Arzua were not very high, 11.47 and 10.99 t/ha, respectively, whereas at Mabegondo the mean production was 14.00 t/ha. It already has been said that in some areas of Galicia the production can increase dramatically if the crop is irrigated.

Winter crops The winter crops (rye, oats, Italian ryegrass and rape) used in the experiment were the most common in the region, with only rape seldom grown in Galicia. In a double cropping system with corn, winter crops take advantage of the fall, winter and spring, giving some production that makes the double cropping advantageous compared with the prairies or monoculture corn.

The type of winter crops which are used in double cropping varies with region. In the cold winter type area, the common crop is rye (57, 123, 247, 278); in milder areas, at least in France and northern Spain, it is Italian ryegrass; and in the U.S., the more commonly reported crops are oats and barley (95, 218, 225, 278, 279). In Galicia, however, rye, oats and Italian ryegrass all are used but in different proportions, depending on the location. Rye is the most common throughout the whole region, but oats and Italian ryegrass are more common in the coastal zones (176). This variation is the reflection of the variability of Galicia.

The yields given by each crop in each location have already been presented in Tables 69, 75, 81, and 87, and they varied depending on the location. The mean yields of rye and oats with vetch seemed to be the most constant throughout locations, between 4.46 and 5.13 t/ha for rye and between 4.88 and 7.31 t/ha for the oats and vetch mixture. In contrast, Italian ryegrass (from 2.96 to 4.29 t/ha) and rape (from 1.17 to 5.63 t/ha) had a lower mean yield but more variation. Most of this variation can be attributed to their low production in Arzua, where the cold winter and the poorer soil fertility harmed both crops. The average of productions for rye, oats with vetch and Italian ryegrass and an ANOVA are presented in Table 97. The results show that oats with vetch was the highest yielding crop, followed by rye and Italian ryegrass although the ANOVA did not show significant differences. Among locations, all had similar average yields, but Arzua was somewhat higher, due to the high performance of the oats-vetch mixture. The winter crops showed more year-to-year variability than corn, but this is normal since corn was considered the main crop and the other plants were harvested when necessary regardless of their yield. Considering the concept, the productions from the winter crops were satisfactory. In France, Raphalen (256, 257) reported Italian ryegrass yields of between 2.7 and 4.9 t/ha for early harvest and between 5.8 and 7.9 t/ha for late harvest. In Belgium, Pieters (247) wrote that rye can produce up to 5 t/ha and Italian ryegrass about 3 t/ha, and in Kentucky (U.S.A.),

Table 97. Overall production comparison of the winter crops (after corn) at different locations

Location	Production (t/ha)
Mabegondo	4.65
Puebla de Brollon	4.51
Arzua	5.04

Crop	Production (t/ha)
Rye	4.77
Oats + vetch	5.80
Italian ryegrass	3.63

Source of variation	d.f.	Sum of squares	F-value	Probability of a greater F
Location	2	2.61	0.18	0.8402
Crop	2	42.47	2.96	0.1629
Crop*Location	4	28.74	--	--
Rep (Locatin)	15	6.65	13.50	0.0001
Error	30	15.97	--	--

Murdock and Wells (218) found a little more than 5 t/ha for oats and barley seeded after and harvested before corn. It is well-known that these crops can get higher productions with delayed harvest, and some double cropping systems have been conducted in that way (57, 279); however, in Galicia this is not common and in our experiments, corn was always considered the main crop.

To select the best of the winter crops is a task that has to be done locally, because yields and quality changed among locations; however, the mixture of oats with vetch seems the more productive at all locations, while Italian ryegrass did very well in Mabegondo and poorly in Arzua. This classification could vary a little if the crop is needed for silage instead of just for green fodder or pasture. Italian ryegrass and the mixture of oats with vetch in a normal-to-good winter environment can lodge and must be harvested or pastured during the midwinter, which reduces their possible silage yield. In this study, lodging occurred at Mabegondo and Puebla de Brollon. Rye never lodged and the whole yield could be harvested at once.

Other quality considerations will be discussed later which can also modify the relative value of the crops.

Prairies Two types of prairies were used in the experiments; one of them was F_2 composed of Italian ryegrass, orchardgrass, red and white clover, and is considered a short-term prairie, very productive during the first year. The second type was the well-known long-term mixture formed by perennial ryegrass and white clover that in Galicia is called F_6. The yields found have been presented in Tables 69, 75, 81 and 87.

On the average, the F_2 mixture produced higher yields than the long-term sward, but they were not significantly different in any location. The mean yields were higher at Mabegondo for both types, where the F_2 produced 13.76 t/ha while the F_6 gave 12.15 t/ha. At Puebla de Brollon, only F_2 was used for the statistical analysis because F_6 failed to grow normally during the first two years; the yield of the F_2 was 10.53 t/ha. At Arzua, the F_2 yielded 11.04 t/ha while the F_6 10.22 t/ha, and at Puenteareas the productions were 11.88 t/ha for F_2 and 10.90 t/ha for F_6. An interesting point already mentioned is the fact that corn and F_6 prairie gave similar yields and corn was never significantly different from any type of prairie.

Comparing both types of prairies, it appears F_2 performed much better than F_6. The F_6 mixture failed to establish correctly at Puebla de Brollon, while the F_2 did not have any problem. At Arzua, the F_6 was easily invaded by the native vegetation, maybe because of the lower soil fertility; and at Puenteareas, the weeds which were mainly Rumex ssp. in 1982 were 43% of the total production. At Mabegondo, however, both types of prairies grew well. This different performance could be due to the different species of the mixture. Normally, Italian ryegrass is very easy to establish and competes very well with weeds; however, perennial ryegrass, although also easy to establish, cannot compete well (128, 341). The F_2 can be seed without any trouble most of the time, while the perennial ryegrass-white clover mixture needs more careful management. This should be an important point when a mixture has to be recommended.

Another type of comparison is the quality of the forage which in this experiment varied somewhat, depending on the location, and reflects the different factors such as climate, weed competition, etc.
In general, when both prairies grew normally, F_6 produced a higher quality crop than did F_2. This could be expected because perennial ryegrass is normally considered a higher quality grass than orchardgrass and sometimes Italian ryegrass. At Mabegondo, the digestibility and crude protein content of F_6 were respectively 70.71% and 17.97%,

while for the F_2 they were 65.93% and 16.26%, respectively. At Arzua, the F_2 had a 14.98% CP and a 65.13% digestibility, while the F_6 had 14.10% CP and 67.86% digestibility. At Puenteareas, the crude protein and ADF for F_2 were 15.52 and 32.69%, respectively, and 16.28 and 33.00% for the F_6. Of all the locations, Mabegondo is the only location at which the F_6 had a normal performance, because at Arzua and Puenteareas the crop had a lot of competition from weeds and native vegetation. However, the large proportion of weeds, higher than 50% at Arzua and about 43% in Puenteareas, did not seem to affect very much the quality of the crop, only about a 2% decrease in crude protein contents and digestibility at Arzua, and higher fiber at Puenteareas. No palatability effects were measured.

The decision about which kind of prairie to seed has to be made locally and depends on the level of management. Where the F_6 can grow normally, it might be better to seed this type, because although it might yield a little less, its quality is much better; and this is a main factor for high animal intake and production (28, 238, 262). However, where the prairie might be more difficult to establish because of weeds or where the level of management is not high, the F_2 might be more appropriate because its chances for failing are small.

The comparison of these results with data published in other areas might not be very accurate because of the varieties used, the climates, the amount of fertilizer, the level of management, etc., may be very different, and this is particularly true for the F_2 mixtures, where practically no comparable data are available. For the perennial ryegrass-white clover mixtures, there is more information. At Mabegondo, yields of about 11.2 t/ha have been shown (106). Some French data (20) presented average yields of about 13 t/ha that can increase to 16.3 t/ha during a good year. In Northern Ireland, the mixture was reported to produce 7.68 t/ha (163) while, in New Zealand, Ball et al. (12) found yields of about 18 t/ha without nitrogen. All these figures reflected the variation due to the particular growing conditions of each area. Compared with those, the yields presented for Galicia could be qualified as normal or maybe normal-low, but the dry summer of the region does not provide the mixtures with the optimum growing conditions.

Crop and rotation quality To have an idea of the quality of the crop, three parameters were determined: crude protein, acid detergent fiber and "in vitro" dry matter digestibility. For this reason, the discussion of the crop quality is going to be limited to these three determinations.

From Tables 72, 78, 84 and 90 which presented the mean yield and quality of the rotations, two points are clear. First, corn is the crop with lower crude protein contents while the prairies were much higher and secondly, corn had similar or higher digestibility than the prairies, while the other crops had lower or higher values depending on the location. The low protein content of corn compared with high content on the prairies is a fact very well-documented (8, 9, 53, 158, 225).

For the whole plant, the average protein for corn ranged from

6.31% at Arzua to 7.62% at Puebla de Brollon, which was the most drought-damaged location. These values are a little low, but in the range of the values reported many times in the literature (9, 53, 218, 225, 301). Another criterion to measure the quality of the crop that has been frequently used is the ear/total plant ratio, whose values normally oscillated between 45 and 65% depending on location, density, time of seeding etc. (26, 61, 100, 142). The values found in Galicia varied depending on the locality and the summer weather. At Mabegondo, the values were between 50.58 and 61.23%, at Puebla between 30.98 and 48.41%, at Arzua between 43.66 and 49.65%, and at Puenteareas they varied from 38.91 in a dry summer to 57.69% under irrigated conditions. The ratios found for Puebla and Arzua might be somewhat low but might reflect the dry summer at Puebla and the poor growing conditions at Arzua.

Most of the IVDMD values reported in the literature are in the range of 60 to 75% (9, 61, 65, 100). The figures obtained in Galicia fall into this range, 71.39% at Mabegondo, 67.82% at Arzua and 65.33% at Puebla, and the higher value at Mabegondo might be because of its higher ear/total plant ratio.

The quality of corn does not change much with advancing stages of maturity, but for the winter crops (rye, oats, ryegrass, etc.), quality can change much depending mainly on the stage of maturity at harvest (44, 53, 269). Also, some crops such as rye and oats are considered to be of lower quality than others (53, 86, 269). The normal reported values for oats and rye are above 70% digestibility and 15-20% crude protein at the vegetative, while at heading most of the reported figures are about 60-65% digestibility and 12-15% crude protein. At maturity, these values decrease to 40 to 50% digestibility and 7 to 8% CP (53, 86, 143, 155, 184, 337). Before comparing these values with the values obtained in Galicia, it should be taken into account that in this experiment the winter crops were considered secondary compared with corn, and they were harvested whenever needed for the corn seeding and not at a particular date or physiological stage; for this reason, some variation should be expected. The digestibilities found at Mabegondo for rye and oats with vetch were about 71% with a CP content of 16% for rye and 19.42% for the oats-vetch mixture, because of the inclusion of vetch. These values varied a little depending on the year, but the quality of the forage produced can be considered good having similar digestibilities to that of corn but with much higher protein contents. On the other hand, although there is not a standard method for the determination of the digestibility and the values can vary, a 60-65% digestibility with adequate supplementation at peak production has been considered adequate to support milk yields of near 5000 kg/ha by holstein cows, and with 70% digestibility, and when consumed at the rate of 3.3% of body weight, milk production is 34 kg/day (28, 262). According to these numbers and considering that the "in vitro" methods try to reflect the "in vivo" digestibilities, the quality of the winter forages at Mabegondo was in general very good and theoretically should allow high milk production. The digestibilities of Italian ryegrass and rape were 79.03 and 81.55%, respectively, and with crude protein contents of about 13%. These digestibility figures were still higher than for rye and oats with vetch. The Brassica crops are reputed to have high digestibilities (15, 77, 143, 154, 277) and at Mabegondo this was true. The Italian ryegrass values were normal for the crop harvested at the leaf stage (3, 144, 287). All these winter forages can be considered of a good quality at Mabegondo with a fair percentage of crude protein. The conclusions reached at Mabegondo are also valid for Puebla de Brollon because the quality determinations were very similar. At Arzua, the digestibility and crude protein percentages were a little lower for rye and oats with vetch, 66% and 68% digestibility for rye and oats with vetch, respectively, while the crude proteins were 11.37 and 12.15%. These values, although a little lower, are still acceptable. Digestibility determinations were not available for Puenteareas. In general, the quality of the winter crops, except for some years and locations, was satisfactory and the digestibilities adequate for milk production (28, 238, 262).

The quality of the crop rotation was a weighted average of the component crops used to calculate the values for the total crop rotation. Since corn was low in protein, the winter crops with their higher protein contents increased the quality of the rotation and at some locations, like Puebla, also increased a little the digestibility.

The quality of the prairies can vary depending on the stage of growth, cutting frequency, etc. In this experiment, as it has been discussed in the previous section, the long-term prairies were normally of better quality than the short-term mixtures, and their digestibility was normally at the same level as corn, although much higher in protein contents. On the other hand, the mean digestibility of the short-term prairies was the lowest of any crop, although their quality could vary depending on the season of the year or by cutting the sward younger and reducing the yield. In general, the long-term prairies produced excellent quality forage, while the short-term mixtures production was relatively low but the quality was of normal-good for animal production. Comparing crop rotations and prairies, the results were a little different depending on the location, but in general the crop rotations had higher digestibilities than the long-term prairies, and of course than the short-term, while the crude protein percentages were lower.

Other factors (fertilization, management, economics) In this section, several aspects of the cropping systems directly or indirectly involved in the experiments will be discussed. One of them is the fertilization of the cropping sequences. This experiment was not a fertilization study, and the amounts of fertilizer used had been recommended in different publications (143). However, after three years, it was found that the soil levels of mainly P and K were higher than values at the beginning of the experiment, particularly for the double cropping systems. At Mabegondo, the initial extractable P was 44.80 ppm while at the end of the experiment no single treatment had lower values and the average was 54.86 ppm. At Puebla de Brollon, the extractable amounts of P were 46.51 ppm at the beginning and 87.31 at the end. At Arzua, the extractable P and K in 1980 were 6.46 and 74.20

ppm, respectively, while in 1983 they were 20.40 and 179.5 ppm, respectively, and at Puenteareas the P went from 46.83 in 1980 to 60.61 ppm at the end of the experiment, while the K raised from 153.31 to 191.75 ppm. The increase was higher on the lower fertility soils, like Arzua or Puenteareas, than at Mabegondo or Puebla de Brollon. Statistically, the values were not very significant, but the trend is clear and its seems to indicate that excessive amounts of P and K were applied and that further research on this aspect is needed. Another fertilization aspect is the partitioning of the P and K for each crop of the sequence. In this experiment, N, P and K were applied for every crop at the seeding time, whereas other reports suggested (218, 225) that P and K could be applied once a year for both crops. This feature should also be a subject of future research in cropping systems.

Double cropping systems have been often criticized for the high labor demand and effort between the harvests of one crop and the seeding of the next (215, 257), and this is almost unavoidable. However, the use of minimum tillage techniques already applied mainly in the U.S. (224, 225) should be the object of study in Galician conditions and could help to facilitate the modern use of double cropping systems.

The economic and sociological aspects of the cropping systems have not been studied in this research; however, these subjects are normally among the most important. A discussion of the cropping systems without, at least, a brief commentary on this theme would not be complete. When comparing different crops for the production of forage, corn normally has been considered an expensive crop while the grazed prairies have been considered (27, 177, 215, 247, 261, 279) the least expensive of the forages for animal production. These are well-known facts; however, the decision about which system to choose, prairies or intensive cropping, depends on the economics of the whole farming unit rather than the cost of the forages by themselves. In a hill land situation, there is really no choice, and the prairies will be the most appropriate crop and are able to produce fair yields of good quality forage. However, in a cropland situation, the election of the system has to be the object of detailed analysis. Some European articles (129) do not find clear justification for further intensifying the animal production of the continent, because of the surplus of animal products already existing in the area. However, the response of the individual farmer to falling prices is the intensification of the production to make the best use of his limited resources, which could be land or labor. When land is the limiting factor, several authors (177, 196, 215, 247) have found that the gross income normally depends on the milk production per unit area, and this is directly related to intensification. On the other hand, when labor is expensive, farmers go to a more extensive system based on permanent pastures. The ideal cropping system for animal production is difficult to decide and the best system will be the one that can take better advantage of the weather, land, and human resources of each particular farm.

SUMMARY AND CONCLUSIONS

This dissertation has been conducted in Galicia (northwestern Spain). This area is mainly characterized by the small size of the farms which has forced farmers to an intensifying type of agriculture. At present, many farmers are mainly dedicated to the production of forages and grain for dairy cattle.

This dissertation, which is divided into two parts, is intended to contribute to the knowledge of the forage production in Galicia. The first part that was called "Summer Crops for Forage Production" was dedicated to the comparison of several summer crops (corn, sunflower, sudangrass, sorghum x sudangrass and alfalfa) for summer forage production. The experiment was conducted at two different areas, Mabegondo and Puebla de Brollon, with different climates and had a duration of four years. The main interest of these crop comparisons was to obtain information about their yields and quality throughout the summer. Corn is the most extensively grown crop of the region, but the other crops might be interesting depending on the locations and circumstances. The overall conclusion of the experiments was that at both locations, corn was the most appropriate crop for summer forage production. At Puebla de Brollon, with a hot-dry summer, corn yielded as much as the other crops but was higher in quality. However, when corn was compared with the total yearly production of alfalfa, this legume produced a better forage crop. The best average time for harvesting corn should be at the beginning of September. The results also suggested that irrigation could greatly increase yields. At

Mabegondo, with milder weather than Puebla, corn was also the best crop in production and quality and should be harvested by October. The experiments showed that this area is not very appropriate for sorghum x sudangrass and sudangrass growth. The overall conclusion was that corn was the most appropriate crop, but the other crops, mainly sunflower, could be adequate at certain dates if other factors, seeding, harvesting time, farm management, economics, etc. are considered.

The second and largest part of the dissertation that was named "Crop Rotations for the Production of Forages" was dedicated to the comparison of forage production and quality of several common rotations and types of pastures. The crop sequences contrasted were 1. corn (alone), 2. corn → rye, 3. corn → oats + vetch, 4. corn → Italian ryegrass, 5. corn → Italian ryegrass → rape, 6. prairies → corn, 7. prairies (short term) and 8. prairies (long term). The experiment was conducted for three years with four climatically different locations: Arzua, Mabegondo, Puebla de Brollon and Puenteareas. The main interest of this research was to obtain information about the forage potential of the area and their relationship with different cropping intensities using the actual recommended agricultural practices.

The overall conclusion of the experiment was that the dry matter yields per unit of area increased with increasing cropping intensity. The double cropping systems always gave higher production than the intermediate type rotations or than the prairies. The results clearly showed that intensification provided greater productions with the actually recommended practices, and that corn was the key crop in this intensification process. Corn was normally the highest yielding crop in the shortest period of time, fitting very well in double cropping systems.

In general, the quality of the crops measured by the crude protein contents, the percentage of acid detergent fiber and the "in vitro" dry matter digestibility was adequate and according to the literature might be able to sustain dairy cows producing about 18 kg/day of milk.

The production potential of the resions were not the same. The areas with mild climate (Mabegondo) produced more than areas with a hot-dry summer (Puebla de Brollon and Puenteareas) or with cooler temperatures and lower levels of fertility (Arzua). However, the data showed that irrigation greatly increased the yields in areas with hot-dry summers (Puenteareas).

The soil analysis at the beginning and at the end of the experiment usually showed an increase in the levels of extractable P and K, indicating that excessive amounts of fertilizer might have been applied and suggesting that further research is needed in the fertilization of intensive cropping systems. Finally, several reports clearly indicate that the double cropping systems provide higher forage production per ha; nevertheless, they are very labor and effort demanding compared with the more extensive systems based on prairies. The ideal cropping system might not be easy to decide, but it is hoped that the data obtained in these experiments will help the farmer take advantage of the climatic conditions, land and human resources of each particular farm.

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APPENDIX A. CLIMATOLOGICAL DATA

Table A1. Temperature (C) and precipitation (mm) measurements in Mabegondo in 1980

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	9.15	22.00	10.25	16.40	8.75	18.40	12.33	0.10	12.05	51.00	15.30	12.10
2nd (11-20 days)	4.55	19.10	9.90	45.60	7.35	23.40	10.25	100.00	11.00	15.40	13.55	25.30
3rd (20-31 days)	11.60	28.60	6.66	28.60	11.72	64.90	10.15	0.00	11.32	8.90	12.75	12.60
Mean temperature or total rainfall	8.43	69.70	8.93	90.60	9.27	106.70	10.91	100.10	11.45	75.30	13.86	50.00

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	13.55	13.30	17.65	1.10	16.70	5.70	16.45	30.40	7.25	20.00	4.35	11.50
2nd (11-20 days)	14.35	19.50	17.60	9.90	16.45	21.30	10.81	71.60	10.85	57.70	8.68	43.40
3rd (20-31 days)	16.45	8.80	20.64	3.50	17.55	36.20	14.00	13.30	8.30	23.90	7.41	68.10
Mean temperature or total rainfall	14.78	41.60	18.63	14.50	16.90	63.20	13.75	115.30	8.80	101.60	6.81	123.00

Table A2. Temperature (C) and precipitation (mm) measurements in Mabegondo in 1981

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	7.35	8.90	8.20	22.20	13.70	28.50	12.85	11.70	12.05	25.50	14.80	23.00
2nd (11-20 days)	8.25	29.60	6.00	25.50	9.70	30.50	11.30	4.20	13.20	55.70	20.30	0.00
3rd (20-31 days)	10.10	0.00	8.25	71.20	12.36	81.50	8.55	28.10	13.45	22.80	16.15	2.20
Mean temperature or total rainfall	8.61	38.50	7.43	118.90	11.94	140.50	10.90	44.00	12.90	104.00	17.08	25.20

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	15.95	14.50	18.35	0.60	19.80	11.50	15.30	44.40	15.25	0.00	11.10	21.20
2nd (11-20 days)	18.45	0.10	19.90	0.00	18.70	35.20	16.60	33.00	14.10	0.00	11.80	96.90
3rd (20-31 days)	18.91	0.10	20.09	0.30	16.05	81.40	12.68	6.70	13.70	0.60	9.77	117.30
Mean temperature or total rainfall	17.81	14.71	19.47	0.90	18.20	136.20	14.79	84.10	14.35	0.60	10.85	235.40

Table A3. Temperature (C) and precipitation (mm) measurements in Mabegondo in 1982

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	14.05	23.20	11.50	4.10	10.25	27.60	13.00	5.90	9.95	9.10	15.90	32.20
2nd (11-20 days)	9.35	24.30	9.20	32.30	9.90	20.40	12.55	0.00	15.20	28.20	17.50	15.00
3rd (20-31 days)	8.73	2.20	11.31	70.30	10.91	0.00	13.60	0.00	16.36	7.10	17.30	18.20
Mean temperature or total rainfall	10.65	49.70	10.64	106.70	10.37	48.00	13.05	5.90	13.92	44.40	16.90	65.40

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	20.00	0.00	19.30	10.80	18.90	0.00	14.40	58.60	14.95	66.50	11.65	22.80
2nd (11-20 days)	18.30	70.80	19.50	2.80	20.72	22.20	14.50	52.80	11.65	59.90	10.55	105.00
3rd (20-31 days)	18.70	1.10	19.40	10.10	15.80	55.51	15.05	17.10	9.60	52.50	8.27	36.80
Mean temperature or total rainfall	19.00	71.90	19.40	23.70	18.48	77.30	14.66	128.50	12.07	178.90	10.10	164.60

Table A4. Temperature (C) and precipitation (mm) measurements in Mabegondo in 1983

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	9.20	13.30	7.47	45.30	12.35	0.40	11.22	57.50	13.30	21.70	17.25	16.10
2nd (11-20 days)	9.05	20.30	5.05	23.80	11.97	17.80	11.12	45.80	11.35	113.10	16.27	0.00
3rd (20-31 days)	11.64	1.90	13.44	33.90	8.86	41.20	10.30	84.20	11.91	17.30	16.32	0.30
Mean temperature or total rainfall	10.02	35.50	8.65	103.00	11.06	59.40	10.88	187.50	12.18	152.10	16.62	16.40

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	17.95	8.40	18.32	16.80	18.07	14.85	16.97	0.80				
2nd (11-20 days)	18.55	17.90	19.17	19.40	16.37	10.70	13.82	33.00				
3rd (20-31 days)	19.23	21.80	19.34	17.05	20.40	0.00	12.95	0.50				
Mean temperature or total rainfall	18.60	48.10	18.46	53.25	18.28	25.55	14.53	34.30				

Table A5. Temperature (C) and precipitation (mm) measurements in Puebla de Brollon in 1980

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	5.35	8.40	10.65	23.80	7.65	11.00	12.95	0.00	12.30	60.20	18.70	14.10
2nd (11-20 days)	2.00	30.10	7.45	40.90	6.75	22.70	10.25	44.60	15.45	28.60	15.30	46.20
3rd (20-31 days)	9.73	73.50	7.72	14.10	11.25	72.00	11.70	2.10	13.04	16.50	14.70	1.80
Mean temperature or total rainfall	5.69	112.00	8.61	78.80	8.56	105.70	11.63	46.70	13.60	105.30	16.23	62.10

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	17.80	18.90	22.75	0.00	19.15	0.00	17.85	24.20	7.15	59.20	4.15	3.30
2nd (11-20 days)	19.10	9.30	20.40	0.00	20.30	0.00	9.40	75.80	9.30	21.40	7.00	119.70
3rd (20-31 days)	21.77	4.80	24.15	0.00	18.25	25.20	17.45	16.20	8.30	27.40	2.30	0.00
Mean temperature or total rainfall	19.56	33.00	22.43	0.00	19.23	25.20	14.90	116.20	8.25	108.00	4.48	123.00

Table A6. Temperature (C) and precipitation (mm) measurements in Puebla de Brollon in 1981

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	1.05	4.20	6.65	10.80	11.75	31.10	12.15	39.40	11.70	43.80	17.20	20.00
2nd (11-20 days)	4.95	29.60	4.85	12.80	13.45	17.40	12.35	21.90	11.50	29.30	23.70	0.00
3rd (20-31 days)	9.70	0.00	6.75	44.30	11.41	66.90	8.70	10.80	14.36	30.40	19.85	0.00
Mean temperature or total rainfall	5.23	33.80	6.08	67.90	12.20	115.40	11.07	72.10	12.52	103.50	20.25	20.00

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	18.50	27.10	20.70	12.80	19.60	8.00	12.80	105.50	12.10	0.00	6.80	50.40
2nd (11-20 days)	20.75	0.00	20.30	0.00	18.75	32.80	15.75	27.60	9.00	0.00	8.35	151.30
3rd (20-31 days)	20.59	0.00	22.00	0.00	13.65	90.40	9.45	2.90	9.05	0.00	7.55	137.30
Mean temperature or total rainfall	19.95	27.10	21.00	12.80	17.33	131.20	12.67	136.00	10.05	0.00	7.57	339.00

Table A7. Temperature (C) and precipitation (mm) measurements in Puebla de Brollon in 1982

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	10.35	45.20	8.80	6.20	7.35	13.60	12.50	13.40	9.00	4.50	17.90	56.00
2nd (11-20 days)	7.15	23.20	6.95	38.20	8.90	9.00	11.45	0.00	15.30	32.40	18.70	10.70
3rd (20-31 days)	4.73	1.60	7.56	46.60	9.77	1.70	12.65	0.00	15.91	26.80	17.80	14.20
Mean temperature or total rainfall	7.41	70.00	7.77	91.00	8.67	24.30	12.20	13.40	13.40	63.70	18.13	80.90

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	23.25	1.00	18.00	0.00	21.85	0.00	11.60	60.40	13.15	51.30	6.15	52.50
2nd (11-20 days)	17.45	24.70	22.40	0.00	21.30	13.80	11.05	59.60	8.15	77.80	7.55	105.10
3rd (20-31 days)	19.00	0.70	19.40	10.00	15.55	78.10	11.95	8.10	7.10	38.60	3.64	23.90
Mean temperature or total rainfall	19.90	26.40	20.20	10.00	19.57	91.90	11.53	128.10	9.47	167.70	5.78	181.50

Table A8. Temperature (C) and precipitation (mm) measurements in Puebla de Brollon in 1983

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	1.00	3.50	4.05	15.00	10.25	0.00	7.90	69.60	10.85	91.00	18.50	10.50
2nd (11-20 days)	2.00	10.80	2.15	30.20	11.50	12.90	10.65	66.10	9.10	111.90	20.15	0.00
3rd (20-31 days)	7.50	0.00	11.62	92.70	7.95	20.40	8.35	138.40	14.35	43.60	19.25	0.00
Mean temperature or total rainfall	3.50	14.30	5.94	137.90	9.90	33.30	8.97	274.10	11.43	246.50	19.30	10.50

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	21.35	32.00	20.30	21.50	21.25	2.00	18.70	0.00				
2nd (11-20 days)	21.20	23.50	19.35	62.60	18.30	8.20	13.85	32.20				
3rd (20-31 days)	20.18	31.90	20.90	19.10	21.85	0.00	13.00	2.40				
Mean temperature or total rainfall	21.08	87.40	20.18	103.20	20.47	10.20	15.18	34.60				

Table A9. Temperature (C) and precipitation (mm) measurements in Presaras (Arzua) in 1980

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	7.95	35.80	9.53	42.70	7.86	30.50	10.67	0.00	11.23	71.20	15.84	23.10
2nd (11-20 days)	3.47	25.10	8.74	37.60	6.31	32.40	10.38	102.40	12.01	22.90	14.03	46.80
3rd (20-31 days)	10.41	89.60	5.62	24.60	9.71	134.30	11.69	0.00	12.25	14.70	13.91	21.50
Mean temperature or total rainfall	7.27	150.50	7.96	104.90	7.96	197.20	10.91	102.40	11.83	108.80	14.59	91.40

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	15.01	52.80	17.91	2.20	17.86	1.90	16.50	54.60	8.00	48.70	4.71	9.20
2nd (11-20 days)	15.88	24.20	18.65	11.50	17.25	42.60	9.33	109.70	9.49	94.80	8.73	178.70
3rd (20-31 days)	17.08	16.80	21.06	3.50	17.23	37.90	14.01	22.50	8.03	28.20	5.74	17.10
Mean temperature or total rainfall	15.99	93.80	19.20	17.20	17.44	82.40	13.28	186.80	8.50	171.70	6.39	205.00

Table A10. Temperature (C) and precipitation (mm) measurements in Presaras (Arzua) in 1981

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	6.34	7.30	6.59	24.10	12.06	53.70	10.61	32.70	9.02	45.40	14.04	32.00
2nd (11-20 days)	6.55	53.10	5.33	28.60	8.03	26.10	10.83	24.20	7.80	94.40	18.42	0.00
3rd (20-31 days)	9.33	0.00	6.46	81.50	10.71	121.90	6.09	27.80	11.52	32.40	15.16	0.80
Mean temperature or total rainfall	7.40	60.40	6.12	134.20	10.26	201.70	9.17	84.70	9.44	172.20	15.87	32.80

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	14.95	1.80	18.42	0.00	18.03	12.50	12.59	104.00	12.44	0.00	8.72	74.00
2nd (11-20 days)	18.69	0.00	20.61	0.00	16.93	37.80	14.91	42.50	11.74	2.50	8.81	205.10
3rd (20-31 days)	18.51	1.70	18.92	0.00	12.70	132.60	10.40	14.40	10.33	0.20	8.01	216.90
Mean temperature or total rainfall	17.38	3.50	19.32	0.00	15.89	182.90	12.63	160.90	11.50	2.70	8.51	496.00

Table A11. Temperature (C) and precipitation (mm) measurements in Presaras (Arzua) in 1982

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	11.11	52.10	7.02	8.00	7.36	22.50	11.63	17.50	8.76	15.00	15.64	35.10
2nd (11-20 days)	7.48	36.60	6.84	54.30	6.95	32.10	11.38	0.60	13.92	55.40	15.99	43.50
3rd (20-31 days)	6.91	8.10	7.03	74.20	9.21	0.00	12.79	0.00	14.61	5.00	15.43	59.00
Mean temperature or total rainfall	8.50	96.80	7.10	136.50	10.29	54.60	11.93	28.10	12.43	75.40	15.68	137.60

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	18.21	3.50	17.98	14.20	18.40	0.00	11.95	95.00	11.94	116.10	9.17	54.60
2nd (11-20 days)	16.71	48.70	18.42	0.50	19.27	23.90	11.85	102.90	9.26	46.90	7.69	156.20
3rd (20-31 days)	12.90	1.10	17.03	12.00	13.61	94.90	12.30	18.60	7.26	63.70	6.10	46.50
Mean temperature or total rainfall	15.94	53.30	17.81	26.70	17.10	118.80	12.03	216.50	9.48	226.70	7.65	257.30

Table A12. Temperature (C) and precipitation (mm) measurements in Presaras (Arzua) in 1983

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	6.28	20.90	5.07	51.20	11.21	0.40	7.80	72.40	11.10	56.80	15.32	25.80
2nd (11-20 days)	6.78	20.70	2.87	20.10	11.08	34.20	9.97	36.00	9.45	142.60	15.72	0.00
3rd (20-31 days)	8.10	3.30	11.11	104.00	8.86	72.20	7.70	141.20	11.00	12.90	17.48	0.10
Mean temperature or total rainfall	7.05	44.90	6.35	175.30	10.38	106.80	8.49	249.60	10.52	212.30	16.17	25.90

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	18.11	17.20	18.20	49.20	17.17	20.30	15.45	1.50				
2nd (11-20 days)	18.67	15.30	17.58	38.30	14.34	17.30	12.12	68.80				
3rd (20-31 days)	18.41	22.40	17.73	24.00	18.44	8.00	10.95	1.00				
Mean temperature or total rainfall	18.40	54.90	17.84	111.50	16.65	45.60	12.84	71.30				

Table A13. Temperature (C) and precipitation (mm) measurements in Puenteareas in 1980

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	18.01	3.00	19.22	0.00	19.50	0.00	17.23	33.00	10.58	34.30	6.45	0.50
2nd (11-20 days)	19.91	22.30	20.72	9.20	18.98	39.20	10.15	53.10	11.08	64.00	8.15	95.00
3rd (20-31 days)	18.89	21.50	22.50	3.50	18.05	16.00	14.05	18.80	8.40	3.40	6.27	3.10
Mean temperature or total rainfall	18.94	46.80	20.81	12.70	18.84	55.20	13.81	104.90	10.02	101.70	6.96	98.60

Table A14. Temperature (C) and precipitation (mm) measurements in Puenteareas in 1981

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	5.52	0.00	7.87	22.00	13.77	43.30	13.42	41.00	12.47	55.70	16.30	26.90
2nd (11-20 days)	8.37	12.80	7.32	5.40	10.32	42.30	12.75	37.50	12.62	68.00	25.05	0.00
3rd (20-31 days)	8.04	0.00	8.84	114.80	13.32	131.00	10.72	7.00	13.91	28.10	19.32	0.00
Mean temperature or total rainfall	7.31	12.80	8.01	142.20	12.47	216.60	12.30	85.50	13.00	151.80	20.22	26.90

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	21.72	0.00	23.27	0.00	21.42	26.00	15.20	133.40	14.40	1.20	9.90	61.00
2nd (11-20 days)	23.51	0.00	23.65	0.00	19.40	39.00	16.62	44.80	13.52	0.20	11.77	254.10
3rd (20-31 days)	22.39	0.00	24.43	0.00	14.83	115.50	13.93	0.50	12.10	2.30	9.80	313.20
Mean temperature or total rainfall	22.54	0.00	23.78	0.00	18.55	180.50	15.25	178.70	13.34	3.70	10.49	628.30

Table A15. Temperature (C) and precipitation (mm) measurements in Puenteareas in 1982

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	13.37	92.00	10.40	14.00			13.30	15.50	12.30	1.10	17.45	7.80
2nd (11-20 days)	8.95	37.40	9.17	80.50			14.57	9.80	16.10	24.00	17.88	36.80
3rd (20-31 days)	8.59	1.40	10.28	62.50			17.10	0.00	19.32	1.00	17.07	49.00
Mean temperature or total rainfall	10.30	130.80	9.95	157.00			14.99	25.30	15.91	26.10	17.47	93.60

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	21.23	26.50	21.47	0.00	21.55	0.00	14.25	78.00	13.92	111.30	9.72	108.50
2nd (11-20 days)	18.49	8.60	21.46	0.00	22.42	30.50	13.07	98.00	11.03	46.00	9.60	99.40
3rd (20-31 days)	19.71	0.00	20.52	14.00	16.34	93.50	14.45	17.00	9.15	63.20	6.91	53.40
Mean temperature or total rainfall	19.81	35.10	21.15	14.00	20.10	124.00	13.92	193.00	11.37	220.50	8.74	261.30

Table A16. Temperature (C) and precipitation (mm) measurements in Puenteareas in 1983

	January		February		March		April		May		June	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	6.82	1.50	7.12	5.00	13.90	0.00	11.13	102.50	13.32	81.00	18.70	36.50
2nd (11-20 days)	7.93	9.50	5.15	9.50	13.87	15.00	12.82	45.50	11.15	144.00	21.90	0.00
3rd (20-31 days)	9.89	0.50	12.84	236.50	11.02	31.00	10.25	157.50	14.73	33.30	20.37	0.00
Mean temperature or total rainfall	8.21	11.50	8.37	251.00	12.93	46.00	11.40	305.50	13.07	258.30	20.32	36.50

	July		August		September		October		November		December	
	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain	Temp.	Rain
1st (1-10 days)	20.40	29.50	21.45	41.00	21.65	9.50	18.35	0.00				
2nd (11-20 days)	20.20	11.00	19.60	18.00	17.70	10.00	15.35	80.00				
3rd (20-31 days)	21.09	10.50	21.64	0.00	20.85	2.00	13.91	9.00				
Mean temperature or total rainfall	20.54	51.00	20.90	59.00	20.07	21.50	15.87	89.00				

APPENDIX B. HARVEST DATES FOR ALFALFA

Table B1. Yield (t/ha) and quality determinations (%) of alfalfa at different harvests)

Date of harvest	Dry matter yield weeds included	Dry matter yield weed free	CP	ADF	IVDMD
7/10/80	3.76	2.62	15.39	36.81	62.42
9/17/80	0.90	0.85	17.55	24.50	67.55
10/30/80	2.21	2.10	30.78	20.18	79.98
4/6/81	2.83	2.40	28.89	29.05	75.34
5/26/81	2.63	1.96	24.82	32.64	68.84
7/21/81	2.99	2.02	15.76	39.85	60.00
9/1/81	0.67	0.64	15.77	34.30	61.42
10/30/81	1.47	1.32	33.20	23.39	75.17
5/13/82	5.84	2.56	17.20	32.30	67.40
6/9/82	2.81	2.33	21.84	33.26	68.73
7/12/82	1.91	1.71	19.01	32.05	68.55
8/31/82	1.35	1.33	16.13	33.56	67.08
10/12/82	0.42	0.31	17.54	39.73	65.63
4/15/83	3.38	1.95	21.95	25.85	70.56
6/21/83	5.26	3.39	14.83	39.15	61.49
8/12/83	2.42	2.42	18.06	37.22	57.80
10/10/83	1.88	1.81	18.76	31.58	65.65

APPENDIX C. PREDICTION EQUATIONS FOR THE CALCULATION OF THE IVDMD

Table C1. Prediction equations for the calculations of the percentages of IVDMD based on CP and ADF

Crop	Number of samples used	CV	R^2	Equation
Corn cob	24	9.74	0.71	$IVDMD = 93.12 - 6.50CP + 7.33ADF + 0.38CP^2 - 0.61ADF^2$
Corn plant	23	3.80	0.61	$IVDMD = 171.76 - 10.16CP - 3.58ADF + 1.01CP^2 - 0.032ADF^2$
Rye	9	3.42	0.86	$IVDMD = 103.96 - 0.08CP - 1.03ADF$
Oats + vetch	12	4.82	0.61	$IVDMD = 327.64 + 0.82CP - 17.41ADF - 0.02CP^2 + 0.28ADF^2$
Italian ryegrass	51	6.82	0.83	$IVDMD = 113.10 - 0.05CP - 1.47ADF$
Rape	15	9.28	0.24	$IVDMD = 220.00 + 2.24CP - 10.62ADF - 0.09CP^2 + 0.18ADF^2$
Short-term prairies (F_2)	103	7.07	0.70	$IVDMD = 110.44 - 0.27CP - 1.31ADF$
Long-term prairies (F_6)	61	7.02	0.68	$IVDMD = 109.48 - 0.14CP - 1.29ADF$